

# Visual Kinship Recognition of Families in the Wild

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**Abstract**—We present the largest database for visual kinship recognition, *Families In the Wild* (FIW), with over 13,000 family photos of 1,000 family trees with 4-to-38 members. It took only a small team to build FIW with efficient labeling tools and work-flow. To extend FIW, we further improved upon this process with a novel semi-automatic labeling scheme that used annotated faces and unlabeled text metadata to discover labels, which were then used, along with existing FIW data, for the proposed clustering algorithm that generated label proposals for all newly added data—both processes are shared and compared in depth, showing great savings in time and human input required. Essentially, the clustering algorithm proposed is semi-supervised and uses labeled data to produce more accurate clusters. We statistically compare FIW to related datasets, which unarguably shows enormous gains in overall size and amount of information encapsulated in the labels. We benchmark two tasks, kinship verification and family classification, at scales incomparably larger than ever before. Pre-trained CNN models fine-tuned on FIW outscore other conventional methods and achieved state-of-the-art on the renowned KinWild datasets. We also measure human performance on kinship recognition and compare to a fine-tuned CNN.

**Index Terms**—Large-scale image dataset, kinship verification, family classification, semi-supervised clustering, deep learning

## 1 INTRODUCTION

VISUAL kinship recognition has an abundance of practical uses, such as issues of human trafficking and in missing children, problems from today's refugee crises, and social media platforms. Use cases exist for the academic world as well, whether for machine vision (e.g., reducing the search space in large-scale face retrieval) or a different field entirely (e.g., historical & genealogical lineage studies). However, to the best of our knowledge, no reliable system exists in practice. This is certainly not due to a lack of effort by researchers, as many works focused on kinship [1], [2], [3], [4], [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26].

Challenges preventing visual kinship recognition from transitioning from research to reality are two-fold:

- (1) Existing data resources for visual kinship are too small to capture true data distributions.
- (2) Hidden factors of visual similarities/differences between blood relatives are complex and less discriminant than in other more conventional problems (e.g., object classification or even facial identification).

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Manuscript received 2 Mar. 2017; revised 22 Jan. 2018; accepted 30 Mar. 2018. Date of publication 12 Apr. 2018; date of current version 10 Oct. 2018. (Corresponding author: Joseph Peter Robinson.)

Recommended for acceptance by S. Escalera, X. Baró, I. Guyon, H. J. Escalante, G. Tzimiropoulos, M. Valstar, M. Pantic, J. Cohn, and T. Kanade.

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Digital Object Identifier no. 10.1109/TPAMI.2018.2826549

Clearly, a large image-set that properly represents families worldwide is needed, which also meets the capacity of more complex, data-driven models (i.e., deep learning), thus, motivating us to build the first large-scale image database for kinship recognition, *Families In the Wild* (FIW). FIW is made-up of rich label information that captures the complex, hierarchical structures of 1,000 unique family trees. Families consist of an average of about 13 photos of each (i.e., over 13,000 family photos), and family sizes range from 3-38 members, with most subjects having multiple samples at various ages (see Fig. 1). FIW is the *largest and most comprehensive* database of its kind.<sup>1</sup>

Deep learning can now be applied to the problem, as we demonstrate on two benchmarks, kinship verification and family classification. We fine-tune deep models to improve all benchmarks, and provide details on the training procedure. We also measure human performance on verification and compare with benchmarks.

We use a multi-modal labeling model to optimize the annotation process. This includes a novel semi-supervised clustering method that works effectively in practice (i.e., generates label proposals for new data using existing labeled data as side information). For this, we increase the amount of available side information using existing labels (i.e., names), labeled faces, and text metadata collected with the family photos. We show a significant reduction in manual labor and time spent on labeling new data.

*Families In the Wild* (FIW) was first introduced in [27]. This work adds to the previous work in a number of ways. Listed here are contributions made in this journal extension:

- (1) Added additional faces for verification and complete families for classification (Section 3).

1. Download FIW via project page, [smile-fiw.weebly.com/](http://smile-fiw.weebly.com/).



Fig. 1. Photos of families sampled randomly from FIW (i.e., 8 of 1,000).

- (2) Improved the labeling process with novel semi-supervised clustering method (Section 4).
- (3) Boosted baseline scores using up-to-date deep learning approaches (Section 5).
- (4) Obtained state-of-the-art on smaller datasets via transferring CNN fine-tuned on FIW (Section 5.5).
- (5) Conducted kinship verification experiment on humans and compared with algorithms (Section 5.6).

## 2 RELATED WORKS

### 2.1 Related Databases

The story of visual kinship recognition begins in 2010, at which time the first kin-based image collection (i.e., CornellKin) was made public [1]. CornellKin included 150 *parent-child* face pairs (i.e., celebrities and their parents). Next, UB KinFace-I & II [16], [28], [29] was introduced to address a slightly different view of kinship recognition—both young and old faces of parents were paired with a child, with a total of 600 face photos of 400 unique subjects (i.e., celebrities and politicians). Then, KinWild I-II [30] was released and used in a 2015 FG Challenge [31], which too focused on *parent-child* pairs. Shortly thereafter, Family101 [7] was introduced as the first attempt of multi-class classification (i.e., *one-to-many*) for kinship recognition. Thus, it is an organized set of structured families [7], including 206 sets of

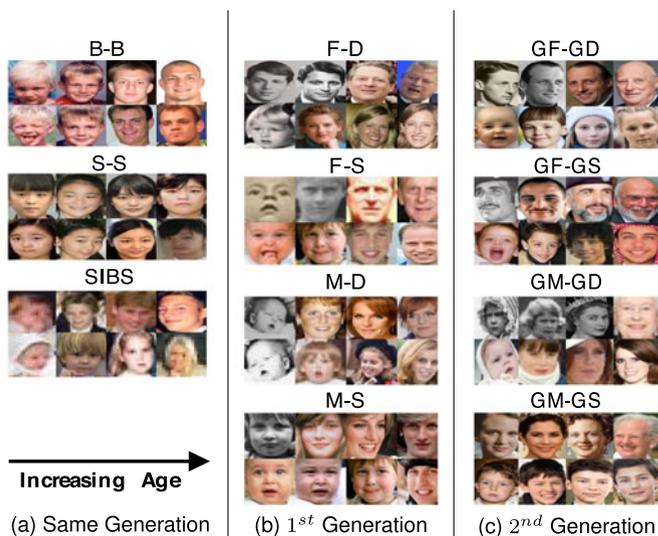


Fig. 2. Samples of 11 pair types of FIW. Each type is of a unique pair randomly selected from a set of diverse families to show variation in ethnicity, while four faces of each individual depict age variations.

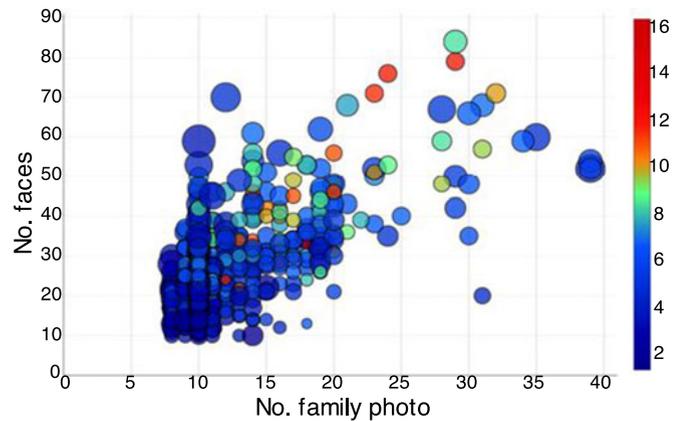


Fig. 3. Database statistics: Horizontal and vertical axes represent counts for photos and faces per family, respectively. Bubble size and color represent counts for members and average faces per member, respectively.

parents and their children (i.e., *core families*) that make up 101 unique family trees. In 2015, TSKinFace [12] was built to support yet another view of kinship recognition, tri-subject verification, where both parents and a child were used—513 Father/Mother-Daughter pairs and 502 Father/Mother-Son pairs (i.e., *two-to-one* verification).

However, there existed no single resource that satisfied the concerns of insufficient data. A single resource with the features of previous works, but in a more complete and abundant manner, was the underlying vision for FIW. As shown in Tables 1 & 2, and discussed in later sections, FIW far exceeds others in terms of number of families, face pairs, and relationship types.

### 2.2 Automatic Kinship Recognition

Fang et al. [1] first attempted kinship verification on *parent-child* face pairs. They proposed selecting the 14 (of 44) most effective hand-crafted features. Following this, researchers recognized that a child's face more closely resembles their parents at younger ages [16], [28], [29]. In response, they used transfer subspace learning methods that uses the younger faces of parents to help fill the appearance gap between their older faces and that of their children. To benchmark the KinWild dataset, Lu et al. [32] proposed a metric learning method used in euclidean space called NRML and its multi-view counterpart (MNRML) that learns a common distance metric for multiple feature types. Fang et al. [7] focused on *one-to-many* (i.e., family classification) by representing faces as a linear combination of sparse features (i.e., feature selection via lasso) of 12 facial parts encoded via a learned dictionary.

Progress made in kinship recognition, along with release of varying task protocols, coincides with an increasing availability of structured and labeled data. Although there have been several significant contributions, none have overcome the challenges posed earlier.

### 2.3 Deep Kinship Recognition

Since the AlexNet CNN [33] won the 2012 ImageNet Challenge [34], deep learning has achieved state-of-the-art in a wide range of machine learning tasks. Central to this frenzy has been facial recognition [35], [36], [37]. In spite of this,

TABLE 1  
Pairwise counts. Table 2 Further Characterizes and Fig. 2 Shows Samples from FIW

	siblings			parent-child				grandparent-grandchild				Total
	B-B	S-S	SIBS	F-D	F-S	M-D	M-S	GF-GD	GF-GS	GM-GD	GM-GS	
KinWild I [32]	0	0	0	134	156	127	116	0	0	0	0	533
KinWild II [32]	0	0	0	250	250	250	250	0	0	0	0	1,000
Sibling Face [51]	232	211	277	0	0	0	0	0	0	0	0	720
Group Face [8]	40	32	53	69	69	62	70	0	0	0	0	395
FIW(Ours) [27]	<b>103,724</b>	<b>39,978</b>	<b>73,506</b>	<b>92,088</b>	<b>129,846</b>	<b>82,160</b>	<b>112,618</b>	<b>7,078</b>	<b>4,830</b>	<b>6,512</b>	<b>4,614</b>	<b>656,954</b>

there are only a few works that use deep learning for kinship recognition [38], [39], [40], [41].

Deep learning has yet to show an advantage for visual kinship recognition, with metric learning seeming more promising. As mentioned in a recent literature review [42], the reason for this stems from an insufficient amount of data. In this work, we include several benchmarks on FIW using deep learning, obtaining a clear advantage in both tasks.

## 2.4 Semi-Automatic Image Tagging & Data Exploration

Automatic image tagging was recently done by first labeling a small amount of the data, and then using it as side information to help guide the clustering process in a semi-supervised manner [43]. Following this, we take advantage of side information from labeled FIW.

Previous works used image captions, whether from Flickr or other sources of images tagged by users, to discover labels and annotate images in an automatic fashion [44]. Generally, methods mining text for image tags treat it as a problem of noisy labels [45], [46]. CASIA-WebFace [47], a large-scale dataset for facial recognition, successfully extended the scale of the renowned LFW [48]. By crawling the web, and leveraging knowledge from IMDB, multiple face samples for 10,000 unique subjects were collected. Although related in the sense of automatic labeling, these problems are very different from the one we present here. We aim to add more data to underrepresented families of the FIW database, and doing so by using the existing labels for each family as side information to guide our semi-supervised clustering method. We wish to maximize the number of labeled faces available to facilitate the clustering in order to generate label proposals. For this, we use the existing FIW labeled faces and the text metadata of the unlabeled data to automatically tag faces using an iterative process governed by both visual and contextual evidence.

TABLE 2  
Family-based Characteristics and Counts

Dataset	No. Family	No. People	No. Faces	Age Varies	Family Trees
CornellKin [1]	150	300	300	×	×
UBKinFace [16], [29]	200	400	600	✓	×
KFW-I [30]	×	533	1,066	×	×
KFW-II [30]	×	1,000	2,000	×	×
TSKinFace [12]	787	2,589	×	✓	✓
Family101 [7]	101	607	14,816	✓	✓
FIW [27]	<b>1,000</b>	<b>10,676</b>	<b>30,725</b>	✓	✓

As discussed in Section 5.4, our method consistently improves with increasing amounts of side information.

## 3 FAMILIES IN THE WILD (FIW) DATABASE

We describe FIW by first reviewing the prior version and old labeling scheme [27], and then introducing the proposed semi-automatic labeling process and Finally, we compare the two.

### 3.1 Existing FIW

Our goal for FIW was to collect about 10 family photos for 1,000 unique families and support with 2 types ground-truth labels, photo-level (i.e., who and where in the image) and family-level (i.e., all members and the relationships between them). Fig. 4 depicts the 2 label types. FIW was organized as follows: each family was assigned a unique ID (i.e., FID), and pictures collected were also assigned a unique ID (i.e., PID). Finally, members added were assigned their own unique ID (i.e., MID). For instance,  $FID_1 \rightarrow MID_1$  in  $PID_1$  refers to the first member of the first family in the first photo collected. The order of IDs was arbitrary, as assignments were made in the order that the family, member, and photo were added. Before introducing the new and improved semi-automatic process, we briefly review the process used initially in [27], which involved 3 steps: (1) *Data Collection*, (2) *Data Labeling*, and (3) *Data Parsing*.

For *Data Collection*, a team of 8 students from different parts of the world, and with vast knowledge of famous persons, compiled a list of families with a primary focus on their place of origin (i.e., an attempt to compile a diverse family list). Table 3 lists the ethnicity distributions of the 1,000 families. Note that this is not the exact distribution, as each family was counted once according to the *root* member for which the search was based (i.e., not per member, but per family). For instance, for Spielberg’s family we consider just Stephen. Future work could entail adding more families from underrepresented ethnic groups, as the distribution still favors Caucasians.

For *Data Preparation*, we built a labeling tool to guide the process of generating the two label types. Labelers would work through all family photos on a family-by-family basis,

TABLE 3  
Ethnicity distribution of FIW. Mix families have > 1 Ethnicities at reference node (e.g., Bruce (Asian) and Linda (Caucasian) Lee)

Caucasian	Spanish/Latino	Asian	African/AA	Arabic	Mix
64%	10.7%	9.1%	8.2%	2.0%	6.0%

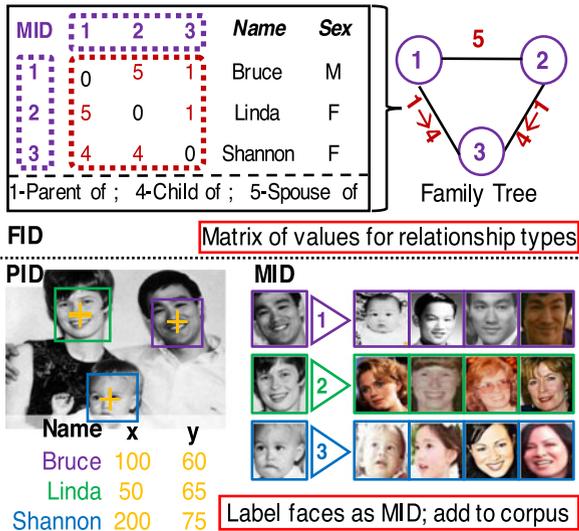


Fig. 4. Visual of the 2 label types of FIW, *Family-level* (FID) and *Photo-level* (PID). FID has individual family member (MID) and relationship information. PIDs contain information of MIDs + their locations in photos.

specifying who was in each photo by clicking member faces and choosing their names from a drop-down menu. Names, genders, and relationships for members were only entered on the first instance in an image—once added to the family the labelers just selected their names each time they appeared in a photo.

For *Data Parsing*, all family photos were detected using classic HOG features trained on top of a linear classifier using image pyramids and sliding windows via DLIB [49]. Faces were cropped and normalized as done in [50], and then resized to  $224 \times 224$ . Finally, the structure of the database was organized into a hierarchy of directories, FID→MID→Face-ID (i.e., 1,000 folders,  $F0001-F1000$ , containing family labels and folders for MIDs with face samples of that member).

Even though it only took a small team to label 10,676 family photos and 1,000 families, the process relied heavily on human input. Plus, in the end, many families were not properly represented (i.e., either too few members, face samples, or family photos). Thus, we aim to reduce the manual labor and overall time requirements to add additional data provided various amounts of labels existed for each (i.e., 61 existing families and 4 replacement). We added replacement families (i.e., newly added families) to make up for cases of overlapping families or an insufficient online presence when searching for photos (i.e., unable to locate family photos for 2 of the under-represented families). Before we propose the semi-automatic labeling model, we first review the two benchmarks included in this work, along with the related statistics of each. We then present the new labeling process that enabled us to add additional data with far less manual labor and in just a fraction of the time.

### 3.2 Data Preparation

Due to the nature of the label structure, FIW can serve as a resource for various types of vision tasks. For this, we benchmark the two popular tracks, kinship verification and family classification. Next, we introduce both of these tasks and the means of preparing the data.

#### 3.2.1 Kinship Verification

Kinship verification aims to determine whether two faces are blood relatives (i.e., kin or non-kin). Prior research mainly focused on *parent-child* pairs (i.e., father-daughter (F-D), father-son (F-S), mother-daughter (M-D), and mother-son (M-S)); some considered sibling pairs (i.e., brother-brother (B-B), sister-sister (S-S), and brother-sister/mixed gender siblings (SIBS)). However, research in both psychology and computer vision revealed that different kin relations render different familial features, which motivated researchers to model different relationship types independently. With the existing image datasets used for kinship verification limited to, at most, 1,000 faces and typically only 4 relationship types, we believe such minimal data leads to overfitting and, hence, models that do not generalize well to unseen data captured *in the wild*. FIW currently supports 11 relationship types (see Fig. 2), 4 being introduced to the research community for the first-time (i.e., *grandparent-grandchild*) and, most importantly, each category contains many more pairs—418,000 face pairs in [27] has increased to 656,954 after extending FIW via the proposed semi-supervised approach.

The 11 relationship types provide a more accurate representation for real-world scenarios. As mentioned, FIW was structured such that the labels can be parsed for different types of tasks and experiments, and additional kinship types can easily be inferred.

#### 3.2.2 Family Classification

Family classification aims to determine the family an unknown subject belongs to. Families are modeled using the faces of all but one family member, with the member left out used for testing. This *one-to-many* classification problem is a challenging problem that gets more challenging with more families. This is because families contain large intra-class variations that typically fool the feature extractors and classifiers, and each additional family further adds to the complexity of the problem. Additionally, and like conventional facial recognition, when the target is unconstrained faces *in the wild* [48] (e.g., the variation in pose, illumination, expression, etc.), the problem continues to become more difficult. In [27], the experiment included only 316 families (i.e., families with 5+ members). In this extended version, we now can include 524 families with the added data. We next present the process followed to extend FIW.

### 3.3 Extending FIW

The proposed semi-supervised model was used to generate label proposals, using existing and newly labeled data as side information for clustering—More side information consistently yields better performance (see Section 5.4 & Fig. 7). Thus, we set out to maximize the amount of side information (i.e., labeled faces) by inferring labels with high confidence by aligning faces and names from the unlabeled photos and metadata. Additionally, we modeled labeled data to discriminate between different family members in a photo. A single family was processed at a time to reduce both the search and label spaces. We aimed to discover labels using evidence from multiple modalities (i.e., visual and contextual). This increased the amount of side information for clustering, and also the sample count modeled and

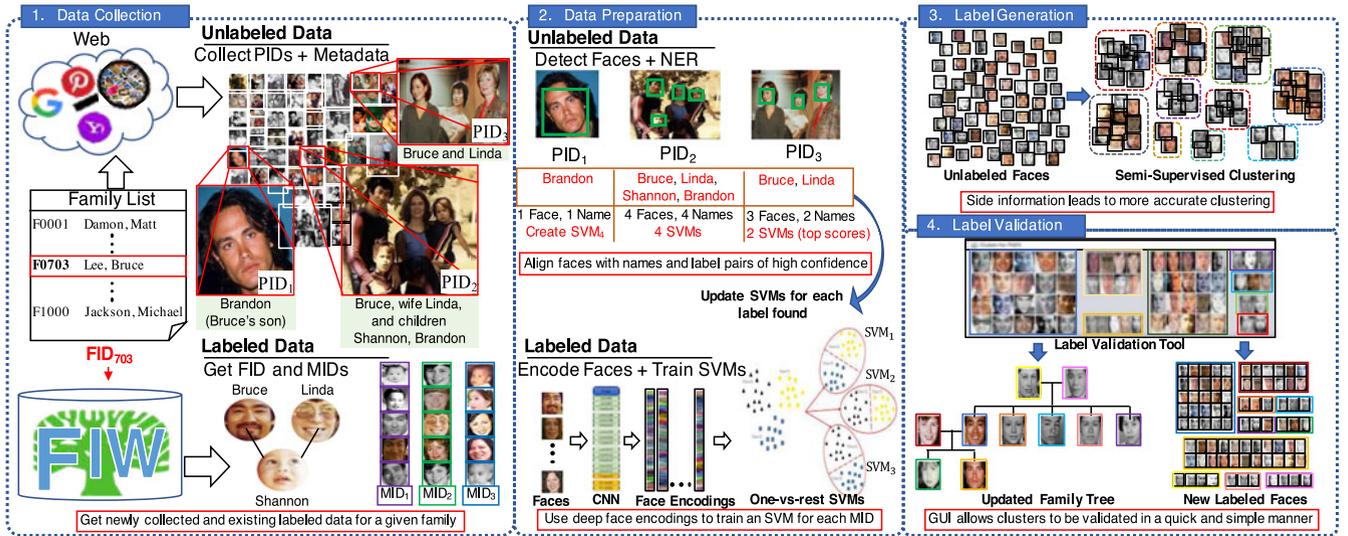


Fig. 5. Semi-automatic labeling pipeline. *Data Collection.* Photos and text metadata were collected for underrepresented families in FIW and assigned unique IDs (i.e., PIDs). Each new member requires at least 1 profile picture (e.g., Brandon in  $PID_1$ ) to add to known labels. *Data Preparation.* With the existing FIW labels, we next aim to increase the amount, both in labeled faces and member labels, using multiple modalities—names in metadata and scores of SVMs were used to automatically label some unlabeled data—face-name pairs were assumed labeled for cases of high confidence. Starting from profile pictures (i.e., 1 face, 1 name) and working towards less trivial scenarios (e.g., 3 faces and 2 names, with 2 faces from 1 member at different ages, like in  $PID_3$ ). This step adds to the amount of side information used for clustering. *Label Generation.* Label proposals for remaining unlabeled faces were generated using the proposed semi-supervised clustering model that leverages labeled data as side information to better guide the process. *Label Validation.* A GUI designed to validate clusters and ensure clusters matched the proper labels.

used to labels more faces. Resulting clusters were then set as ground truth upon human verification in *Step 4*.

We demonstrate the effectiveness of the new labeling scheme by comparing the number of user inputs (i.e., mouse clicks and keystrokes) and overall time with the process followed in [27]. It took just a few inputs and a few minutes on average per family, opposed to hundreds of inputs and several minutes to over an hour (see Table 2).

We next explain the improved multi-modal scheme made-up of 4 steps: (1) *Data Collection*, (2) *Data Preparation*, (3) *Label Generation*, and (4) *Label Validation*. The goal of (1) and (2) is to gather and increase the amount of side information available for (3), while (4) is to ensure correct labels for all new data. In other words, we set out to increase the labeled sample pool (i.e., side information) by inferring labels for unlabeled faces, which adds to the set of training exemplars. The faces that were still unlabeled in (3) were clustered using all labels as side information. All newly added data is then verified by a human. The process is illustrated in Fig. 5, which we next describe step-by-step.

### 3.3.1 Step 1: Data Collection

The goal was to add data to under-represented families (i.e., families with few members, faces, or family photos). There were 65 families extended in total, with 1 family replaced due to limited available data and 3 merged together to remove overlaps. For instance, Catherine, Duchess of Cambridge, and her immediate family merged with the Royal family since she shares 2 kids with Prince William. Many new labels and relationships resulted from this merge alone (i.e., the Royal family grew from 29 to 38 members). See Fig. 3 and Table 3 for FIW statistics.

In preparation of *Step 2*, we set 2 requirements for the data collection: (1) rich text metadata describing subjects in each photo and (2) 1 profile photo per new member. Profile

photos enabled label expansion for each new members (i.e., single faces and single names align with higher confidence).

### 3.3.2 Step 2: Data Preparation

The goal here was to maximize the amount of side information available for clustering in *Step 3*. Thus, we took advantage of both labeled (i.e., faces & names) and unlabeled data (i.e., detected faces & text metadata) to automatically infer labels for many unlabeled faces (see *Data Preparation* in Fig. 5). We next describe each component involved in this step.

*Text metadata* (i.e., image captions) were collected with for all photos in *Step 1*. With this, a list of names for each family was generated via a Name Entity Recognition (NER) classifier [52]. Then, a *Look-Up-Table* (LUT) of candidate names for each member was generated—i.e., keys as member IDs (MIDs) and values as possible references to that member (e.g., *Bruce* aka *Bruce Lee* aka *Brandon's father*). One challenge stemmed from name variations (e.g., a person legally named *Joseph* might be called *Joe*); additionally, there were name titles (e.g., *Queen Elizabeth II* might be called *Elizabeth II*, *Elizabeth*, or, in older photos, *Princess Elizabeth*). Additionally, nicknames posed additional challenges (e.g., *Robert Gronkowski*, commonly referred to by his nickname *Gronk*). To address this, a LUT with detected references for each subject was first compiled, and then further augmented with additional tags (e.g., adding titles and surnames). LUTs were later referenced to find evidence in the text metadata of a member's presence in a photo.

*New MIDs* found in profile photos (e.g.,  $PID_1$  in Fig. 5)—when processing a family, each image that has a single face detected and just one name in its metadata was considered a profile photo. Profile photos were processed first. The name detected in the metadata was compared to all names for members stored in the LUTs. If there were no matches, the subject was then added as a

TABLE 4  
Previous and New (bold) Labeling Processes Summarized by Required Inputs (Keyboard + Mouse Clicks) and Time

	Bruce Lee	Michael Jordan	John Malone	Craig Mccaw	Marco Reus	British Royal	Michael Jackson	Total
Inputs (count)	551	97	153	178	35	1,838	1,272	4,124
<b>Inputs (count)</b>	<b>12</b>	<b>6</b>	<b>10</b>	<b>15</b>	<b>7</b>	<b>21</b>	<b>24</b>	<b>95</b>
Time (h:m:s)	0:15:08	0:5:31	0:5:18	0:6:16	0:4:24	1:25:23	0:44:52	2:46:52
<b>Time (h:m:s)</b>	<b>0:1:11</b>	<b>0:0:31</b>	<b>0:1:05</b>	<b>0:0:56</b>	<b>0:0:31</b>	<b>0:6:44</b>	<b>0:7:13</b>	<b>0:18:11</b>

new member in that family. A LUT of names was then generated for each new member, and the name of highest frequency (i.e., number of detections in all metadata) recorded as the name corresponding to their assigned MID (e.g.,  $MID_6$  for the sixth member).

*Unlabeled and labeled faces* were encoded as 4,096D features from the  $fc_7$ -layer of the pre-trained VGG-Face CNN model [36]. *One-vs-rest Support Vector Machine (SVM)* models were trained for each member using labeled samples from all other members of that family as the negatives. Next, profile photos were processed (i.e., 1 name and 1 face). Names that match an existing label were added to corresponding MID data pools, while mismatched names were added as a new MID with a LUT generated. This shows the benefit of including profile pictures for each new member, which makes it so all family members were known. It is important to note that SVMs were updated each time a new labeled face was added.

*Discovering labels* continues in a similar fashion, except now the SVMs play a more critical role. Now moving on to images with 2 faces and 2 names, the 2 SVMs of the respective members were used to classify the 2 faces. Provided high scores and no conflicts, labels were inferred. Cases with low confidence or conflicts were skipped, leaving those faces to be labeled via clustering. Next, photos with 3 faces and 3 names were processed, then 4 faces and 4 names, and so on and so fourth. After all one-to-one cases were processed, photos with a different number of names and faces were processed. For each photo, only SVMs that correspond to a LUT with matching names were used. Thus, justifying a requirement of *Step 1*—collect rich metadata in terms of specifying members present in photos.

It should also be noted that some families benefited far more than others in this process. Nonetheless, roughly 25 percent of the 2,973 added faces were correctly labeled by this simple multi-modal process.

### 3.3.3 Step 3: Label Generation

Label proposals were generated for unlabeled faces using the proposed semi-supervised clustering method. To get the most out of our model we automatically labeled additional data in *Step 2*, while identifying all new members being added to each family. Hence, the number of members (i.e.,  $k$ ) was known for each family.

See Section 4 for details (i.e. objective function and solution).

### 3.3.4 Step 4: Label Validation

Finally, clusters (i.e., labels) were validated by a human. This was a three-part process: assign an MID to each cluster; validate each cluster, which was displayed in a grid of faces in the order of confidence score; specify gender and

relationships of newly added members. As shown in Fig. 5, a JAVA interface was designed to generate ground-truth for new data with just a few clicks of the mouse and minimal time per family. The inputs were cluster assignments for a family, with faces listed in order of confidence (i.e., cosine distance from centroid). MIDs were assigned in *Step 2* (i.e., inferred from text, SVM scores, or both), which must also be validated. The outputs were labels for each PID and an updated relationship matrix (Fig. 4).

### 3.3.5 Discussion

Seven families of various sizes were used to compare the old [27] and proposed labeling schemes—old scheme took 4,124 inputs in about 2.75 hours, and just 95 inputs in about 18.1 minutes via the new (see Table 4). Collecting and labeling the data for the extended FIW was done by a single person in days; it initially took a small team several months with the old scheme. Thus, demonstrating a significant savings in manual labor and time (note that greater amounts of data was originally collected, however, relative savings in time and manual labor clearly yields from process used in this extended version). One future direction is to use the proposed to extend FIW with family videos. It can also be used to further extend existing families to extend the number of families, which, if on the order of thousands or more, then automating *Step 1* could reduce savings (i.e., web scrape for family information (e.g., *Wiki*) and photos (e.g., *Google*, *Bing*, etc.)).

## 4 SEMI-SUPERVISED FACE CLUSTERING

Labeling data is typically a labor intensive and financially expensive task required for related problems. We aim to accelerate the process leveraging labeled data. We now demonstrate the novel semi-supervised clustering algorithm proposed for labeling. Let  $X = x_i$ , be the data matrix with  $n$  instances and  $m$  features, and  $S$  be the  $n' \times K'$  matrix used as side information matrix, with  $n'$  labeled samples from  $K'$  classes (i.e. families). Our goal was to make use  $S$  to guide the  $K'$  classes to  $K$ , where  $K' \leq K$ .

### 4.1 Objective Function

Inspired by our previous work [43], [53], a partition level constraint is used to make the learnt partition agree with partial human labels as much as possible. To demonstrate the effectiveness of our labeling mode, K-means with cosine similarity is employed as the core clustering method to handle high-dimensional data due to its high efficiency and robustness. The following is our objective function,

$$\min \sum_{k=1}^K \sum_{x_i \in \mathcal{C}_k} f_{\cos}(x_i, m_k) + \lambda U_c(S, H \otimes S), \quad (1)$$

where  $f_{\cos}$  is the cosine similarity,  $H$  is the final partition,  $H_S = H \otimes S$  is part of  $H$  with instances also in the  $S$ ,  $m_k$  is the centroid of  $C_k$ ,  $U_c$  is the renowned Categorical Utility Function [54] and  $\lambda$  is the trade-off parameter.

To better understand the last term in Eq. (1), we give the detailed calculation of  $U_c$ . Given two partitions  $S$  and  $H_S$  containing  $K'$  and  $K$  clusters, respectively. Let  $n_{kj}^{(S)}$  denote the number of data objects belonging to both cluster  $C_j^{(S)}$  in  $S$  and cluster  $C_k$  in  $H_S$ ,  $n_{k+} = \sum_{j=1}^{K'} n_{kj}^{(S)}$ , and  $n_{+j} = \sum_{k=1}^K n_{kj}^{(S)}$ ,  $1 \leq j \leq K'$ ,  $1 \leq k \leq K$ . Let  $p_{kj}^{(S)} = n_{kj}^{(S)}/n'$ ,  $p_{k+} = n_{k+}/n'$ , and  $p_{+j} = n_{+j}^{(S)}/n'$ . We then have a normalized contingency matrix (NCM), based on which a wide range of utility functions can be accordingly defined. For instance, the widely used category utility function can be computed as follows:

$$U_c(H_S, S) = \sum_{k=1}^K p_{k+} \sum_{j=1}^{K'} \left( \frac{p_{kj}^{(S)}}{p_{k+}} \right)^2 - \sum_{j=1}^{K'} (p_{+j}^{(S)})^2. \quad (2)$$

It is worthy to note that  $U_c$  measures the similarity of two partitions, rather than two instances. The larger value of  $U_c$  indicates the higher similarity.

## 4.2 Solution

We notice that the first term in Eq. (1) is the standard K-means with cosine similarity. Could we still apply K-means optimization to solve the problem in Eq. (1)? The answer is yes! Due to our previous work [55], we provide a new insight of  $U_c$  by the following lemma.

**Lemma 1.** *Given a fixed partition  $S$ , we have*

$$U_c(H_S, S) = -\|S - H_S G\|_F^2 + \text{constant}, \quad (3)$$

where  $G$  is the centroid matrix of  $S$  according to  $H_S$ .

By the above lemma, the second term in Eq. (1) can also be transformed into a K-means problem with squared euclidean distance. Then a K-means-like algorithm can be used on the augmented matrix with modified distance function and centroid update rule for the final partition.

First an augmented matrix  $D$  is introduced as follows:

$$D = \begin{bmatrix} X_S & S \\ X_T & 0 \end{bmatrix} \text{ with } X = \begin{bmatrix} X_S \\ X_T \end{bmatrix}, \quad (4)$$

where  $d_i$  is the  $i$ th row of  $D$ , which has of two parts,  $d_i^{(1)}$  and  $d_i^{(2)}$  (i.e.,  $d_i^{(1)} = (d_{i,1}, \dots, d_{i,d_m})$  presents the feature space and  $d_i^{(2)} = (d_{i,d_m+1}, \dots, d_{i,d_m+K'})$  denotes the label space). Zeros in  $D$  are the artificial elements, rather than the true values so that all zeros contribute to the computation of the distance and centroids, which inevitably interfere the cluster structure. To make the zeros in  $D$  not involved in the calculation, we give the new update rule for the centroids of  $D$ . Let  $m_k = (m_k^{(1)}, m_k^{(2)})$  be the  $k$ th centroid  $C_k$  of  $D$ , we modify the computation of centroids as follows:

$$m_k^{(1)} = \frac{\sum_{d_i \in C_k} d_i^{(1)}}{|C_k|}, \quad m_k^{(2)} = \frac{\sum_{d_i \in C_k} d_i^{(2)}}{|C_k \cap X_S|}. \quad (5)$$

with the distance function is also adjusted as

$$f(d_i, m_k) = f_{\cos}(d_i^{(1)}, m_k^{(1)}) + \mathbf{1}(d_i \in S) f_{sqE}(d_i^{(2)}, m_k^{(2)}), \quad (6)$$

where  $\mathbf{1}$  returns 1 if the condition is satisfied, otherwise 0.

The correctness and convergence of the modified K-means is similar to one in [43].

## 5 EXPERIMENTS

We conduct the following experiments: benchmark kinship verification and family classification; evaluate the proposed semi-supervised clustering method; fine-tune CNNs using FIW and evaluate on KinWild I & II (i.e., transfer-learning); measure human performance on kinship verification and compare to top scoring algorithms.

The subsequent sections are organized as follows. First, we review the visual features, metric learning methods, and deep learning that is common in all experiments. Then, we dive into the experiments mentioned above. We introduce each independently, but with the same structure: experimental settings, experiment-specific training philosophy, and then the results and analysis.

### 5.1 Experimental Setting

For the sake of organization, all low-level features and metric learning approaches used throughout are listed and described in this section. Most are in two or more experiments, however, even those used for verification, for example, are still treated as common information, and thus is described alongside other items of preliminary information. Following concepts pertaining to “shallow” vision methodology, we review specifications of the pre-trained CNNs used as off-the-shelf feature extractors.

#### 5.1.1 Feature Representations

Detected and aligned faces were normalized and encoded using low-level and CNN-based features. We next describe the descriptors used in this work—SIFT, LBP, pre-trained VGG-Face and ResNet CNNs—each having been widely used in visual kinship and facial recognition problems.

SIFT [66] is amongst the most widely used feature type in object and face recognition. Here we follow the settings of [30]: resize images to  $64 \times 64$ , then extract features from  $16 \times 16$  blocks with a stride of 8 (i.e., 49 blocks that yields  $128 \times 49 = 6,272D$  face feature).

LBP [56] are renown for its effectiveness in tasks such as texture analysis and face recognition. We again follow the settings of [30]: resize images to  $64 \times 64$ , divide into  $16 \times 16$  non-overlapping blocks, and use a radius of 2 and sampling number of 8. Each block is represented as a  $256D$  histograms (i.e.,  $256 \times 16 = 4,096D$  face encoding).

VGG-Face [36], a pre-trained CNN with the topology of VGG-16: made-up of small convolutional kernels (i.e.,  $3 \times 3$ ) with a convolutional stride of 1 pixel. VGG-Face is trained on 2.6M face images of 2,622 different celebrities. VGG has worked well on various face databases—97.3 percent in accuracy on *YouTube Faces* [67]; 98.95 percent accuracy on *Labeled Faces in the Wild* [68]. By removing the top two layers—softmax and last fully-connected layer (aka fc8-layer or  $f_{c8}$ )—the CNN can be used as an *off-the-shelf* face encoder

TABLE 5  
Averaged Verification Accuracies (%) for 5-Fold Experiment on FIW with No Family Overlap Between Folds

Method	siblings			parent-child				grandparent-grandchild				Acc. $\pm$ Std.
	B-B	S-S	SIBS	F-D	F-S	M-D	M-S	GF-GD	GF-GS	GM-GD	GM-GS	
LBP [56]	55.52	57.49	55.39	55.05	53.77	55.69	54.65	55.79	55.92	54.00	55.36	55.33 $\pm$ 1.01
SIFT [57]	57.86	59.34	56.91	56.37	56.24	55.05	56.45	57.25	55.35	57.29	56.74	56.80 $\pm$ 1.17
ResNet-22 [58]	65.57	69.65	60.12	59.45	60.27	61.45	59.37	55.37	58.15	59.74	59.70	61.34 $\pm$ 3.81
VGG-Face [36]	69.67	75.35	66.52	64.25	63.85	66.43	62.80	62.06	63.79	57.40	61.64	64.89 $\pm$ 4.68
+ITML [59]	57.15	61.61	56.98	58.07	54.73	57.26	59.09	62.52	59.60	62.08	59.92	59.00 $\pm$ 2.44
+LPP [60]	67.61	66.22	71.01	62.54	61.39	65.04	63.54	63.50	59.96	60.00	63.53	64.03 $\pm$ 3.32
+LMNN [61]	67.11	68.33	66.88	65.66	67.08	68.07	66.16	61.90	60.44	63.68	60.15	65.04 $\pm$ 3.00
+GmDAE [62]	68.05	68.55	67.33	66.53	68.30	68.15	66.71	62.10	63.93	63.84	63.10	66.05 $\pm$ 2.36
+DLML [63]	68.03	68.87	67.97	65.96	68.00	68.51	67.21	62.90	63.96	63.11	63.55	66.19 $\pm$ 2.36
+mDML [41]	69.10	70.15	68.11	67.90	66.24	70.39	67.40	65.20	<b>66.78</b>	63.11	63.45	67.07 $\pm$ 2.44
ResNet+CF [64]	69.88	69.54	69.54	68.15	67.73	71.09	68.63	<b>66.37</b>	66.45	<b>64.81</b>	64.39	67.87 $\pm$ 2.15
SphereFace [65]	<b>71.94</b>	<b>77.30</b>	<b>70.23</b>	<b>69.25</b>	<b>68.50</b>	<b>71.81</b>	<b>69.49</b>	66.07	66.36	64.58	<b>65.40</b>	<b>69.18</b> $\pm$ 3.68

[69]. Thus, models were trained on an auxiliary resource and used on the target data. We extracted face features from fc7-layer (i.e., 4, 096D).

ResNet-22 [58] is a 22-layer residual CNN trained on CASIA-Webface [47]. ResNet-22 has a different network topology than VGG (i.e., more layers made possible via skipping connections in residual blocks to ensure that the signal stays intact by superimposing an identity tensor). Faces were fed through to layer  $fc_5$  (512D encoding).

### 5.1.2 Metric Learning

Metric learning is commonly used and, sometimes, designed for kinship problems. Four metric learning and graph embedding methods used previously for face-based problems are include: Information theoretic metric learning (ITML) [59], Discriminative Low-rank Metric Learning (DLML) [63], Locality Preserving Projections (LPP) [60], and Large Margin Nearest Neighbor (LMNN) [61].

### 5.1.3 Deep Learning

*Fine-Tuned CNNs.* Centerface (CF) [58] loss enhances the discriminative power of deeply learned features by adding a supervision signal to reduce the intra-class variations. SphereFace uses an angular softmax loss, and has most recently claimed state-of-the-art in facial recognition [65]. We fine-tune both these CNNs on FIW.

Additionally, we include two state-of-the-art methods based on autoencoders (AE), graph regularized marginalized Stacked AE (GmDAE) [62], and marginalized denoising AE based metric learning (mDML) [41].

## 5.2 Kinship Verification

Kinship verification is a binary classification problem (i.e., *true* or *false*, aka *kin* or *non-kin*, respectfully). It is the *one-to-one* view of kinship recognition, which is explained next.

### 5.2.1 Experimental Setting

The protocol we followed is conventional in face-based tasks: 5-fold cross validation with no family-overlap between folds. There are 11 relationship types evaluated (statistics and types shown in Table 1).

For each pair type, we added negative (i.e., *non-kin*) pairs to the 5-folds—we randomly mismatched pairs in each fold until the number of negative and positive pairs are the same

in each fold (i.e., negative pairs are added at random until it makes up 50 percent of the respective fold). Thus, the total number of positive and negative labels are equivalent.

For this task we included each feature, metric learning approach, and deep learning model listed above. We then fine-tuned the pre-trained CNN models on the FIW dataset, which is described in detail in the next section. To compare features, we computed cosine similarity between each pair, which was then compared to a threshold to classify each pair as either *kin* or *non-kin*.

Verification accuracy (i.e., average of 5-folds) and *receiver operating characteristic* (ROC) curves were used to evaluate.

### 5.2.2 Training Philosophy

For ResNet-22 + CF, we fine-tuned the Centerface model on our FIW data. Training was done using four Titan X GPUs with a batch size of 256. The learning rate was initially set to 0.01, then drops to 0.001 and 0.0001 at the 800 and 1200 iterations, respectively. Training was complete after 1,600 iterations. The weight decay was set to 0.0005. For SphereFace [65], the settings are similar to ResNet-22+CF (i.e., same batchsize, learning rate, weight decay, and number of iterations), and with the angular margin set to 4.

### 5.2.3 Results

As listed Table 5, *siblings* pairs types tended to score the highest, followed by *parent-child* types, and then *grandparent-grandchild*. Thus, the wider the generational gap, the wider between appearances of faces.

SphereFace, which was fine-tuned on FIW, outperformed other benchmarks with an average accuracy of 69.18 percent, which is 1.31 and 2.11 percent better than ResNet-22+CF and mDML, respectively, which were top the scoring methods prior to the recent release of SphereFace. Also, out of the pre-trained CNNs, VGG-Face scored 3.55 percent higher than ResNet-22, and both outperformed the low-level features (i.e., LBP & SIFT). From such, encodings from VGG-Face were used as features for the metric learning and AE methods. Besides LMNN and DLML, which improved score by 0.15 and 1.30 percent, the other metric learning methods actually worsened the performance of the descriptors extracted from the pre-trained VGG-Face CNN. This infers that faces encoded via VGG-Face are more discriminative when used *off-the-shelf* than when certain metrics are learned on top.

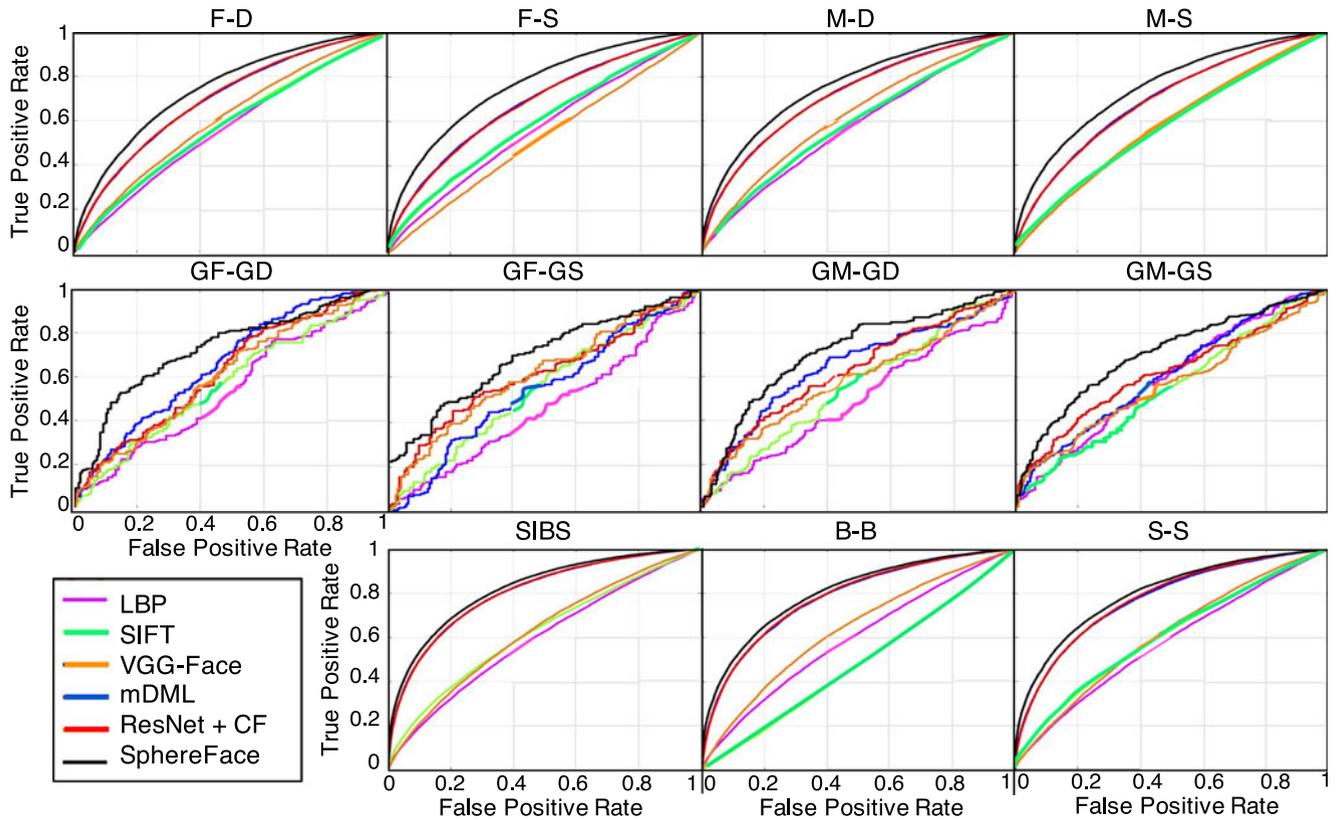


Fig. 6. Relationship type specific ROC curves. The plots show that the SphereFace CNN trained on FIW as the best benchmark.

We show a significant boost in performance when fine-tuning CNNs on FIW data—all features from CNNs outperform the conventional shallow methods. The results show that the deep learning models better encode the complex representation needed to discriminate between *kin/non-kin* (see Fig. 6). An improvement to these benchmarks, perhaps via a deep network designed specifically for this task, is certainly a direction for future work.

### 5.3 Family Classification

Family classification is a *one-to-many* problem. The goal is to determine which family an unseen subject came from. In other words, a set of families with a missing member to the model is provided. Then, the missing (i.e., unseen) members get classified as being from one of the families (i.e., closed form, as we currently assume that all members at test time belongs to one of the families modeled during training). We next review some details for this task.

#### 5.3.1 Experimental Setting

Data from 564 families by leaving a different single member out in each fold for testing, while data from all the other members were used for training (i.e., leave-one-out w.r.t. family members). Families with at least 5 members were used. Thus, the data was split into 5-folds with no family overlap between folds (i.e., a minimum of 4 family members for training and 1 for testing). Each fold contained roughly 2,700 images—about that many faces used to test each split, while about the rest, about 12,800 faces, were used for training (i.e., a total of 13,420 images).

#### 5.3.2 Training Philosophy

VGG-Face and ResNet-22 CNNs were fine-tuned on FIW by replacing the loss layers of the pre-trained CNNs with a softmax loss to predict the 564 family classes. There were a few differences: VGG-16 used a fixed learning rate of 0.0001, a batch size of 128, and trained for 800 iterations on one Titan X GPU; ResNet-22 used the same batch size and number of iterations, but with a larger learning rate 0.001, which was fixed too. For ResNet-22 + CF and SphereFace, we followed the same training process used for verification.

#### 5.3.3 Results

We report the accuracy scores for five runs (see Table 6). As shown, the top-1 accuracy for modeling *one-vs-rest* linear SVMs on top of deep VGG-Face features was just 3.04 percent. Then, by replacing the softmax layer to target the number of families (i.e., 564), and fine-tuning on FIW, the top-1 accuracy was improved (i.e., +7.38 to 10.42 percent). ResNet-22, also fine-tuned by replacing softmax layer, showed the second to highest accuracy with 14.17 percent, which outscored the top performing CNN on verification (i.e., SphereFace). The top performance was with the fine-tuned ResNet-22 using Centerface loss with 16.18%.

### 5.4 Proposed Semi-Supervised Clustering

To demonstrate the effectiveness of our semi-supervised model, we cluster FIW data using various amounts of *family-level* labels as side information. We simulate two settings for evaluation—all data and just unlabeled data—shown as bold and dotted lines, respectively (see Fig. 7).

TABLE 6  
Classification Accuracy Scores (%) for 564 Families

Run ID	Network(s)	Acc.
Run-1	VGG-Face, $fc_7$ (4,096D)+one-vs-rest SVMs	3.04
Run-2	VGG-Face, replaced softmax (564D)+fine-tuned	10.42
Run-3	ResNet-22 + softmax (564D)	14.17
Run-4	SphereFace (564D)	13.86
Run-5	ResNet-22 + CF (512D) + softmax (564D)	<b>16.18</b>

#### 5.4.1 Experimental Setting

We used 23,979 faces from 996 family classes. Faces were encoded using a pre-trained VGG-Face (i.e.,  $fc_7$ ). We varied the ratio of unlabeled data to side information across the horizontal axis up to 50 percent percent of labeled clusters, while the  $y$ -axis denotes the clustering performance on the rest of the unlabeled data by NMI. We compared to a pairwise constrained clustering method, LCVQE [70], which is also a K-means-based constrained clustering method and transforms the partition level side information into ‘must-link’ and ‘cannot-link’ constraints. We used K-means as a baseline (i.e., no side-information).

#### 5.4.2 Results

Fig. 7 shows that more side information consistently boosts the performance of our method. Even on the unlabeled data, our method exceeds the K-means baseline, which further validates the effectiveness of using our method in semi-automatic labeling scenarios. For LCVQE, the pair-wise constraints make the cluster structure unpredictable, vulnerable to deviate from the true one, and, thus, perform worse than the baseline. This shows that imposing hard constraints on side information, like ‘must-link’ and ‘cannot-link’, may even damper results. On the contrary, our model leverages the side information to only only improve when more is added.

### 5.5 Transfer-Learning Experiment

To demonstrate that FIW generalizes well, we fine-tune the ResNet CNN model on the entire dataset and assess the model on a smaller, non-overlapping image collection. Specifically, we achieve state-of-the-art performance using a fine-tuned CNN to encode faces of the renown KinWild datasets (see Table 7). For KinWild I, we get a 4 percent increase in performance (i.e., from 78.4 to 82.4 percent). For KinWild II, there is a 5.6 percent improvement to 86.6 percent.

Notice the boost in accuracy on KinWild-I for F-D compared to other types. Clearly, the small sample size of this dataset does not properly represent the data distribution of these pair types, while FIW has noticeably less variance between scores of parent-child types. Regardless of the high score of *Bar Ilan University* (BIU) for type F-D, our fine-tuned network performs better on all other types, in average accuracy, and while providing less variation in type-specific scores. Again, this variance is considered to be caused by a small sample size, as there is less variation in score for the parent-child types of FIW.

### 5.6 Human Performance on FIW

We evaluate human performance on kinship verification with a subset of FIW pairs. Although others conducted similar experiments [29], [30], [71], this was done with a larger

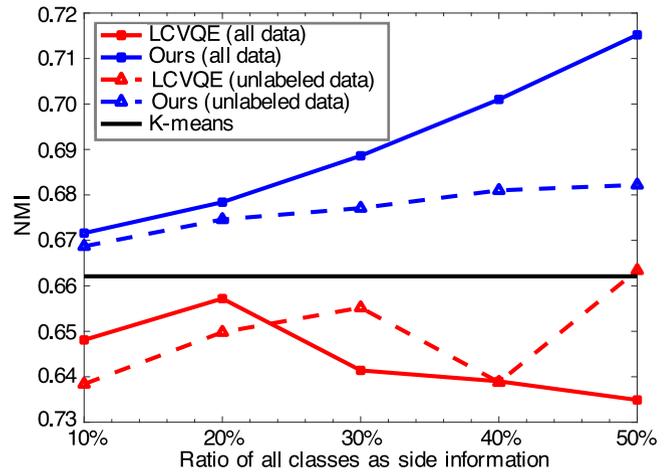


Fig. 7. Results for clustering families using different amounts of side information. As clearly depicted, our method obtains the top performance. Moreover, a distinct increase in NMI for our method is shown with an increase in the amounts of side information.

sample set made up of more relationship types (*Case 1*). Additionally, an evaluation was done for the Boolean case only (*Case 2*). We now discuss experimental settings, results, and analyses of both human experiments.

#### 5.6.1 Experimental Setting

First a list of pairs from FIW with a fair data distribution was sampled (i.e., different and diverse families with faces of various ages). Faces for both positive and negative pairs were from different photos, with samples used in either just once. Also, we used no more than one positive and negative sample per member. We rigorously examined and, in some ways, handcrafted the list to best control the experiment (i.e., replaced face images of poorer quality and famous people). Thus, efforts were spent to better ensure a fair, unbiased assessment. We also only used faces to avoid evidence besides facial appearance influencing human responses [72]. The same list of images was used for both cases: evaluating pairs per specific relationship types and for the Boolean case only.

A Google Form was used to collect responses, and the university and social media networks to recruit volunteers. Answers were anonymous, although demographic information was collected (i.e., ethnicity, country of origin, and gender). Some volunteers completed both experiments. However, scores and answers were not revealed. Also, there was nearly a year between when the two experiments were conducted, with the Boolean case being a follow-up experiment to analyze how specific relationship types influence responses. Users chose from predefined responses: *Related*, *Unrelated*, or *Skip*. Participants were asked to *Skip* if they had prior knowledge of one or both subjects, regardless of knowledge about the relationships (i.e., skip any pair containing an identifiable face). Face pair-types were processed in no special order: a type-by-type basis for *Case 1*, then shuffled at random for *Case 2*. There was a total of 406 face pairs sampled from the 11 categories. Specifically, there were 50 for each *sibling* type (i.e., 150 in total), 36 for each *parent-child* type (i.e., 144 in total), and 28 for each *grandparent-grandchild* (i.e., 112 in total).

We had 75 and 110 volunteers for *Case 1* and *2*, respectively. No training of any sort was provided. In both cases,

TABLE 7  
Verification Accuracy (%) for KinWild I & II. Notice that Centerface (i.e., ResNet + CF) Trained using FIW and then Fine-Tuned on Kin-Wild Significantly Outperformed other Methods

Method	KinWild-I					KinWild-II				
	FD	FS	MD	MS	Avg.	FD	FS	MD	MS	Avg.
LBP [56]	72.8	79.5	71.7	68.1	73.0	70.8	78.4	69.0	73.2	72.9
SIFT [57]	73.9	81.4	76.4	71.1	75.7	72.2	78.8	82.2	79.6	78.2
NRML (LBP)	81.4	69.8	67.2	72.9	72.8	79.2	71.6	72.2	68.4	72.9
NRML (HOG)	83.7	74.6	71.6	80.0	77.5	80.8	72.8	74.8	70.4	74.7
BIU (LBP)	85.5	76.5	69.9	74.4	76.6	84.2	79.5	76.0	77.0	79.2
BIU (HOG)	<b>86.9</b>	76.5	70.6	79.8	78.4	87.5	80.8	79.8	75.6	81.0
VGG-Face [36]	72.0	77.6	78.3	80.6	77.1	68.8	74.4	76.6	74.6	73.6
ResNet + CF	78.0	<b>83.7</b>	<b>87.0</b>	<b>80.8</b>	<b>82.4</b>	<b>87.7</b>	<b>86.0</b>	<b>86.7</b>	<b>87.4</b>	<b>86.6</b>

the distribution of demographics was approximately 45 percent Caucasian, 35 percent Asian, 10 percent Hispanic/Latino, 4 percent African American, and 1 percent Arab; 65 percent born in the United States, 30 percent from China, and 1-2 percent from South America, Middle East, and the Philippines; 55 percent males and 45 percent Females. No specific demographics were targeted (i.e., a matter who volunteered on social media, per request of the authors, etc.). Future work could involve a greater emphasis on demographics. Here, we hope to lay the framework for such a study, along with other interesting directions that assessing human ability to recognize kinship can take.

To compare human performance to benchmarks, we fine-tune SphereFace CNN on the 764 families that were not included in face pairs used for the human evaluation.

### 5.6.2 Results

We assess both human evaluations via box plots (see Fig. 8).

In *Case 1*, the minimum scores across most categories are below random (i.e.,  $< 50\%$ ). In response, we confirmed that no single person scored lowest in more than 1 of the 9 categories. Another observation is the distribution of averages, and its mean of 57.5 percent, had the smallest variance—no

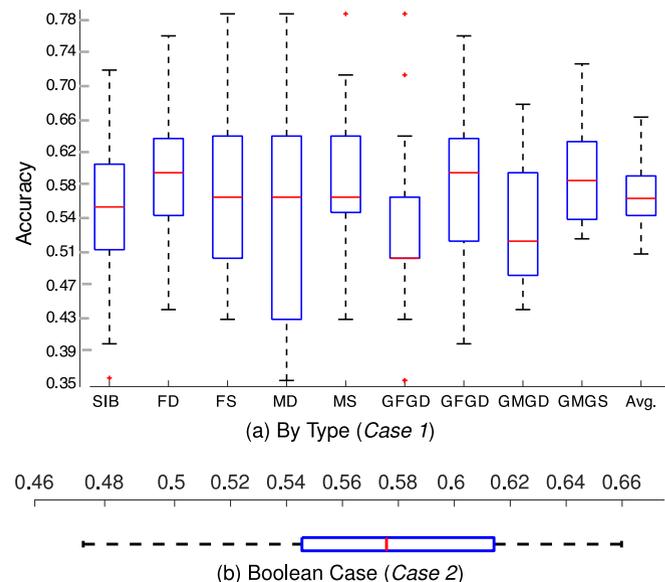


Fig. 8. Box plot for humans on kinship verification. *Case 1*: Relationship type dependent evaluations. *Case 2*: Evaluations with type unspecified.

average below 50 percent or above 67.5 percent, which indicates that no single, or more than a few subjects, dominated the average scores for the better of the worse. Examining the pairs where errors were made, three conclusions can be made: (1) especially for relationship types spanning 1 or more generations (i.e., parents and grandparents), the common pairs consistently marked incorrectly are cases where the face of the expected elder is at a younger age or the face of the descendant appears older (e.g., grandfather in his thirties and grandson in his fifties); (2) different ethnic groups typically made common mistakes on face pairs of different backgrounds; (3) females often deviated from males on the mistakes made that are common and across different ethnic groups—varying females were always the top scorer, but never the same twice. Apparently, nature and nurture can play a role in humans' ability to do kinship verification as well. There are many interesting directions for future work (e.g., even larger and more diverse subject pool, or samples with added semantics like full body views or entire photos with background context).

For *Case 2*, we evaluated humans' ability to recognize kinship in faces, but, this time, without specifying the relationship. From this, we were aiming to determine whether the relationship direction and face age impacted human responses. Overall, the mean values barely changed, however, the set of pairs commonly marked wrong did—relationship direction does seem to worsen human ability to recognize kinship when the direction of the relationship contradicts with the age appearance of face pairs; however, in cases without the age contradiction, knowledge of the relationship type helps humans to determine whether or not the face pairs are of that type (i.e., even though the set of common pairs incorrectly classified changed, the overall mean did not, as the average fell between 57-58 percent in both cases). Fig. 9 shows face pairs most commonly classified correctly or incorrectly considering both cases.



Fig. 9. Samples used for human evaluation. Each column displays pairs most commonly marked correctly and incorrectly, and in cases for where the correct answer were true and false. Each of these pairs were properly classified by the fine-tuned CNN.

Quantitatively, human performers scored an average of 57.5 percent. This is comparable to hand-crafted features such as LBP and SIFT, but nearly 15 percent lower than our fine-tuned CNN (i.e., the SphereFace CNN fine-tuned for this experiment scores 72.15 percent).

## 6 DISCUSSION AND FUTURE WORK

The label structure of FIW are dynamic—labels can be parsed to use the data in various ways. For instance, siblings can be split between those who share one and both parents. Even a slight change in paradigm can drastically change the study—use both parents for verification (i.e., tri-subject verification [12]); use child photos only to test with for family classification. Besides, we still need to improve our visual recognition capability for kinship in current benchmarks. Then, it only seems natural to aim for fine-grained categorization of entire family trees (i.e., the ultimate achievement). On a different note, generative modeling is another interesting research track to pursue (e.g., given a couple and predict the offspring, or samples of their baby and predict the baby's appearance as an adult). Even other pair types (e.g., great- and great-great-grandparents, cousins, aunts, uncles, etc.). Also, the labeling framework introduced in this work could be used to add video data to the families of FIW, which can be served as a resource for template-based search and retrieval, or even consider emotional responses and facial expressions of family members.

We expect that as researchers advance this problem, FIW and its uses too will advance, and especially when considering the potential for interdisciplinary collaborations—Whether nature-based studies, generative or predictive modeling, or security-based. We hope FIW inspires new types of problems, and anticipate the list of uses to only grow when FIW is in the hands of researchers worldwide. In the end, the aim here is to attract more experts to the problem of kinship recognition.

## 7 CONCLUSION

*Families In the Wild* is the first large-scale dataset available for visual kinship recognition. We annotated complex hierarchical relationships with only a small team in a fast and efficient manner—providing the largest labeled collection of family photos to-date. FIW was structured to support multiple tasks with its dynamic label structure. We provided several benchmarks for kinship verification and family classification. Pre-trained CNNs were used as *off-the-shelf* face encoders, which outperformed conventional methods. Results for both tasks were further improved by fine-tuning the CNN models on FIW. We measured human observers and compared their performance to the machine vision algorithms, showing that CNN models already surpass humans in recognizing kinship.

The size of FIW, along with the labels for 1,000 complex family trees, makes it difficult to pinpoint the exact directions FIW will lead. Improving upon the benchmarks is one route, which is the focus of past, current, and future data challenges based on FIW. Also, additional task evaluations (e.g., search & retrieval and tri-subject), along with cross-discipline studies (e.g., nature-based and human perception) are also promising directions.

## REFERENCES

- [1] R. Fang, K. D. Tang, N. Snavely, and T. Chen, "Towards computational models of kinship verification," in *Proc. 17th IEEE Int. Conf. Image Process.*, 2010, pp. 1577–1580.
- [2] X. Chen, L. An, S. Yang, and W. Wu, "Kinship verification in multi-linear coherent spaces," *Multimedia Tools Appl.*, vol. 76, pp. 4105–4122, 2015.
- [3] Y. Chen, H. Hu, S. Cao, and B. Ma, "Sparse coding based kinship recognition," in *Proc. 4th Int. Conf. Multimedia Technol.*, 2015, Art. no. 115.
- [4] A. Dehghan, E. Ortiz, R. Villegas, and M. Shah, "Who do I look like? determining parent-offspring resemblance via gated autoencoders," in *Proc. IEEE Conf. Comput. Vis. Pattern Recognit.*, 2014, pp. 1757–1764.
- [5] X. Duan and Z.-H. Tan, "A feature subtraction method for image based kinship verification under uncontrolled environments," in *Proc. Int. Conf. Image Process.*, 2015, pp. 1573–1577.
- [6] X. Duan and Z. H. Tan, "Neighbors based discriminative feature difference learning for kinship verification," in *Proc. Int. Symp. Visual Comput.*, 2015, pp. 258–267.
- [7] R. Fang, A. Gallagher, T. Chen, and A. Loui, "Kinship classification by modeling facial feature heredity," in *Proc. Int. Conf. Image Process.*, 2013, pp. 2983–2987.
- [8] Y. Guo, H. Dibeklioglu, and L. van der Maaten, "Graph-based kinship recognition," in *Proc. 22nd Int. Conf. Pattern Recognit.*, 2014, pp. 4287–4292.
- [9] J. Hu, J. Lu, J. Yuan, and Y.-P. Tan, "Large margin multi-metric learning for face and kinship verification in the wild," in *Proc. Asian Conf. Comput. Vis.*, 2014, pp. 252–267.
- [10] L. Kou, X. Zhou, M. Xu, and Y. Shang, "Learning a genetic measure for kinship verification using facial images," *Math. Problems Eng.*, vol. 2015, 2015, Art. no. 472473.
- [11] Q. Liu, A. Puthenputhussery, and C. Liu, "Inheritable Fisher vector feature for kinship verification," in *Proc. IEEE 7th Int. Conf. Biometrics Theory Appl. Syst.*, 2015, pp. 1–6.
- [12] X. Qin, X. Tan, and S. Chen, "Tri-subject kinship verification: Understanding the core of a family," *IEEE Trans. Multimedia*, vol. 17, no. 10, pp. 1855–1867, 2015.
- [13] T. F. Vieira, A. Bottino, and I. U. Islam, "Automatic verification of parent-child pairs from face images," in *Proc. Progress Pattern Recognit. Image Anal. Comput. Vis. Appl.*, 2013, pp. 326–333.
- [14] T. F. Vieira, A. Bottino, A. Laurentini, and M. De Simone, "Detecting siblings in image pairs," *The Visual Comput.*, vol. 30, no. 12, pp. 1333–1345, 2014.
- [15] X. Wang and C. Kambhampettu, "Leveraging appearance and geometry for kinship verification," in *Proc. IEEE Int. Conf. Image Process.*, 2014, pp. 5017–5021.
- [16] S. Xia, M. Shao, and Y. Fu, "Kinship verification through transfer learning," in *Proc. 22nd Int. Joint Conf. Artif. Intell.*, 2011, pp. 2539–2544.
- [17] M. Xu and Y. Shang, "Kinship verification using facial images by robust similarity learning," *Math. Problems Eng.*, vol. 2016, 2016, Art. no. 4072323.
- [18] H. Yan, J. Lu, W. Deng, and X. Zhou, "Discriminative multimetric learning for kinship verification," *IEEE Trans. Inf. Forensics Security*, vol. 9, no. 7, pp. 1169–1178, Jul. 2014.
- [19] H. Yan, J. Lu, and X. Zhou, "Prototype-based discriminative feature learning for kinship verification," *IEEE Trans. Cybern.*, vol. 45, no. 11, pp. 2535–2545, Nov. 2015.
- [20] L. Zhang, K. Ma, H. Nejati, L. Foo, T. Sim, and D. Guo, "A talking profile to distinguish identical twins," *Image Vis. Comput.*, vol. 32, no. 10, pp. 771–778, 2014.
- [21] X. Zhou, J. Hu, J. Lu, Y. Shang, and Y. Guan, "Kinship verification from facial images under uncontrolled conditions," in *Proc. 19th ACM Int. Conf. Multimedia*, 2011, pp. 953–956.
- [22] X. Zhou, Y. Shang, H. Yan, and G. Guo, "Ensemble similarity learning for kinship verification from facial images in the wild," *Inf. Fusion*, vol. 32, pp. 40–48, 2016.
- [23] Y. Wu, Z. Ding, H. Liu, J. Robinson, and Y. Fu, "Kinship classification through latent adaptive subspace," in *Proc. 13th IEEE Int. Conf. Autom. Face Gesture Recognit.*, 2018, pp. 143–149.
- [24] M. Shao, S. Xia, and Y. Fu, "Identity and kinship relations in group pictures," in *Human-Centered Social Media Analytics*. Berlin, Germany: Springer, 2014, pp. 175–190.

- [25] J. Zhang, S. Xia, M. Shao, and Y. Fu, "Family photo recognition via multiple instance learning," in *Proc. ACM Int. Conf. Multimedia Retrieval*, 2017, pp. 424–428.
- [26] S. Xia, M. Shao, and Y. Fu, "Toward kinship verification using visual attributes," in *Proc. 21st Int. Conf. Pattern Recognit.*, 2012, pp. 549–552.
- [27] J. P. Robinson, M. Shao, Y. Wu, and Y. Fu, "Families in the wild (FIW): Large-scale kinship image database and benchmarks," in *Proc. ACM Multimedia Conf.*, 2016, pp. 242–246. [Online]. Available: <http://doi.acm.org/10.1145/2964284.2967219>
- [28] S. Xia, M. Shao, J. Luo, and Y. Fu, "Understanding kin relationships in a photo," *IEEE Trans. Multimedia*, vol. 14, no. 4, pp. 1046–1056, Aug. 2012.
- [29] S. X. M. Shao and Y. Fu, "Genealogical face recognition based on UB kinface database," in *Proc. IEEE CVPR Workshop Biometrics*, 2011, pp. 60–65.
- [30] J. Lu, X. Zhou, Y.-P. Tan, Y. Shang, and J. Zhou, "Neighborhood repulsed metric learning for kinship verification," *IEEE Trans. Pattern Anal. Mach. Intell.*, vol. 36, no. 2, pp. 331–345, Feb. 2014.
- [31] J. Lu, J. Hu, V. E. Liong, X. Zhou, A. Bottino, I. Ul Islam, T. Figueiredo Vieira, X. Qin, X. Tan, S. Chen, et al., "The FG 2015 kinship verification in the wild evaluation," in *Proc. 11th IEEE Int. Conf. Workshops Autom. Face Gesture Recognit.*, 2015, pp. 1–7.
- [32] J. Lu, J. Hu, X. Zhou, J. Zhou, M. Castrillón-Santana, J. Lorenzo-Navarro, L. Kou, Y. Shang, A. Bottino, and T. Figueiredo Vieira, "Kinship verification in the wild: The first kinship verification competition," in *Proc. IEEE Int. Joint Conf. Biometrics*, 2014, pp. 1–6.
- [33] A. Krizhevsky, I. Sutskever, and G. E. Hinton, "Imagenet classification with deep convolutional neural networks," in *Proc. Int. Conf. Neural Inf. Process. Syst.*, 2012, pp. 1097–1105.
- [34] O. Russakovsky, J. Deng, H. Su, J. Krause, S. Satheesh, S. Ma, Z. Huang, A. Karpathy, A. Khosla, M. Bernstein, et al., "Imagenet large scale visual recognition challenge," *Int. J. Comput. Vis.*, vol. 115, no. 3, pp. 211–252, 2015.
- [35] L. Wolf, "DeepFace: Closing the gap to human-level performance in face verification," in *Proc. IEEE Conf. Comput. Vis. Pattern Recognit.*, 2014, pp. 1701–1708.
- [36] O. M. Parkhi, A. Vedaldi, and A. Zisserman, "Deep face recognition," in *Proc. Brit. Mach. Vis. Conf.*, vol. 1, no. 3, p. 6, 2015.
- [37] F. Schroff, D. Kalenichenko, and J. Philbin, "FaceNet: A unified embedding for face recognition and clustering," in *Proc. IEEE Conf. Comput. Vis. Pattern Recognit.*, 2015, pp. 815–823.
- [38] K. Zhang, Y. Huang, C. Song, H. Wu, and L. Wang, "Kinship verification with deep convolutional neural networks," in *Proc. Brit. Mach. Vis. Conf.*, Sep. 2015, pp. 148.1–148.12.
- [39] A. Dehghan, E. G. Ortiz, R. Villegas, and M. Shah, "Who do I look like? determining parent-offspring resemblance via gated autoencoders," in *Proc. IEEE Conf. Comput. Vis. Pattern Recognit.*, 2014, pp. 1757–1764.
- [40] C. Xiong, L. Liu, X. Zhao, S. Yan, and T.-K. Kim, "Convolutional fusion network for face verification in the wild," *IEEE Trans. Circuits and Syst. Video Technol.*, vol. 26, no. 3, pp. 517–528, 2016.
- [41] S. Wang, J. P. Robinson, and Y. Fu, "Kinship verification on families in the wild with marginalized denoising metric learning," in *Proc. 12th IEEE Int. Conf. Workshops Autom. Face Gesture Recognit.*, 2017, pp. 216–221.
- [42] X. Wu, E. Boutellaa, X. Feng, and A. Hadid, "Kinship verification from faces: Methods, databases and challenges," in *Proc. IEEE Int. Conf. Signal Process. Commun. Comput.*, 2016, pp. 1–6.
- [43] H. Liu and Y. Fu, "Clustering with partition level side information," in *Proc. Int. Conf. Data Mining*, 2015, pp. 877–882.
- [44] C. W. Leong, R. Mihalcea, and S. Hassan, "Text mining for automatic image tagging," in *Proc. 23rd Int. Conf. Comput. Linguistics: Posters*, 2010, pp. 647–655.
- [45] E. Law, B. Settles, and T. Mitchell, "Learning to tag using noisy labels," in *Proc. Eur. Conf. Mach. Learn.*, 2010, pp. 1–29.
- [46] D. Wang, S. C. Hoi, Y. He, and J. Zhu, "Mining weakly labeled web facial images for search-based face annotation," *IEEE Trans. Knowl. Data Eng.*, vol. 26, no. 1, pp. 166–179, Jan. 2014.
- [47] D. Yi, Z. Lei, S. Liao, and S. Z. Li, "Learning face representation from scratch," arXiv preprint arXiv:1411.7923, 2014.
- [48] G. B. Huang, M. Ramesh, T. Berg, and E. Learned-Miller, "Labeled faces in the wild: A database for studying face recognition in unconstrained environments," Univ. Massachusetts, Amherst, MA, Tech. Rep. 07–49, Oct. 2007.
- [49] D. E. King, "Dlib-ml: A machine learning toolkit," *J. Mach. Learn. Res.*, vol. 10, pp. 1755–1758, 2009.
- [50] V. Kazemi and J. Sullivan, "One millisecond face alignment with an ensemble of regression trees," in *Proc. IEEE Conf. Comput. Vis. Pattern Recognit.*, 2014, pp. 1867–1874.
- [51] A. Bottino, M. De Simone, A. Laurentini, and T. F. Vieira, "A new problem in face image analysis: Finding kinship clues for siblings pairs," *ICPRAM*, vol. 2, 2012, pp. 405–410.
- [52] J. R. Finkel, T. Grenager, and C. Manning, "Incorporating non-local information into information extraction systems by gibbs sampling," in *Proc. 43rd Annu. Meeting Assoc. Comput. Linguistics*, 2005, pp. 363–370.
- [53] H. Liu, Z. Tao, and Y. Fu, "Partition level constrained clustering," *IEEE Trans. Pattern Anal. Mach. Intell.*, 2017, doi: 10.1109/TPAMI.2017.2763945.
- [54] B. Mirkin, "Reinterpreting the category utility function," *Mach. Learn.*, vol. 45, pp. 219–228, 2001.
- [55] J. Wu, H. Liu, H. Xiong, J. Cao, and J. Chen, "K-means-based consensus clustering: A unified view," *IEEE Trans. Knowl. Data Eng.*, vol. 27, no. 1, pp. 155–169, Jan. 2015.
- [56] T. Ahonen, A. Hadid, and M. Pietikainen, "Face description with local binary patterns: Application to face recognition," *IEEE Trans. Pattern Anal. Mach. Intell.*, vol. 28, no. 12, pp. 2037–2041, Dec. 2006.
- [57] N. Dalal and B. Triggs, "Histograms of oriented gradients for human detection," in *Proc. IEEE Comput. Soc. Conf. Comput. Vis. Pattern Recognit.*, Jun. 2005, pp. 886–893.
- [58] Y. Wen, K. Zhang, Z. Li, and Y. Qiao, "A discriminative feature learning approach for deep face recognition," in *Proc. Eur. Conf. Comput. Vis.*, 2016, pp. 499–515.
- [59] J. V. Davis, B. Kulis, P. Jain, S. Sra, and I. S. Dhillon, "Information-theoretic metric learning," in *Proc. 24th Int. Conf. Mach. Learn.*, 2007, pp. 209–216.
- [60] X. Niyogi, "Locality preserving projections," in *Proc. Int. Conf. Neural Inf. Process. Syst.*, 2004, Art. no. 153.
- [61] K. Q. Weinberger and L. K. Saul, "Distance metric learning for large margin nearest neighbor classification," *J. Mach. Learn. Res.*, vol. 10, no. Feb, pp. 207–244, 2009.
- [62] Y. Peng, S. Wang, and B.-L. Lu, "Marginalized denoising autoencoder via graph regularization for domain adaptation," in *Proc. Int. Conf. Neural Inf. Process.*, 2013, pp. 156–163.
- [63] Z. Ding, S. Suh, J.-J. Han, C. Choi, and Y. Fu, "Discriminative low-rank metric learning for face recognition," in *Proc. 11th IEEE Int. Conf. Workshops Autom. Face Gesture Recognit.*, 2015, pp. 1–6.
- [64] J. P. Robinson, M. Shao, H. Zhao, Y. Wu, T. Gillis, and Y. Fu, "Recognizing families in the wild (RFIW)," in *Proc. Workshop Recognizing Families Wild*, 2017, pp. 5–12.
- [65] W. Liu, Y. Wen, Z. Yu, M. Li, B. Raj, and L. Song, "Sphereface: Deep hypersphere embedding for face recognition," in *Proc. IEEE Conf. Comput. Vis. Pattern Recognit.*, 2017, pp. 6738–6746.
- [66] D. G. Lowe, "Distinctive image features from scale-invariant keypoints," *Int. J. Comput. Vis.*, vol. 60, pp. 91–110, 2004.
- [67] L. Wolf, T. Hassner, and I. Maoz, "Face recognition in unconstrained videos with matched background similarity," in *Proc. IEEE Conf. Comput. Vis. Pattern Recognit.*, 2011, pp. 529–534.
- [68] G. B. Huang, M. Ramesh, T. Berg, and E. Learned-Miller, "Labeled faces in the wild: A database for studying face recognition in unconstrained environments," Univ. Massachusetts, Amherst, MA, Tech. Rep. 07–49, 2007.
- [69] J. P. Robinson and Y. Fu, "Pre-trained D-CNN models for detecting complex events in unconstrained videos," in *Proc. SPIE Commercial+ Sci. Sens. Imaging*, 2016, pp. 98 7100–98 7100.
- [70] D. Pelleg and D. Baras, "K-means with large and noisy constraint sets," in *Proc. Eur. Conf. Mach. Learn.*, 2007, pp. 674–682.
- [71] M. F. Dal Martello and L. T. Maloney, "Where are kin recognition signals in the human face?" *J. Vis.*, vol. 6, no. 12, pp. 1356–1366, 2006.
- [72] L. Best-Rowden, S. Bisht, J. C. Klontz, and A. K. Jain, "Unconstrained face recognition: Establishing baseline human performance via crowdsourcing," in *Proc. IEEE Int. Joint Conf. Biometrics*, 2014, pp. 1–8.



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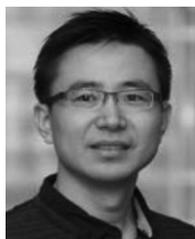
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