Face Recognition in Forensics and Beyond

Anil K. Jain

Department of Computer Science & Engineering
Michigan State University
Birth to Age 10 in 85 Seconds

Why Face?

- Face recognition: most common human experience
- Social interaction: expression, emotion, intent, age
- Easy to capture: covert acquisition (surveillance)
- Legacy databases: passport, visa, driver license
Automated Face Recognition

Given a query face image (probe), identify it from a target population (gallery)

Probe

Gallery

MATCH

1:1 vs. 1:N matching
Where is Face Recognition Today?

De-duplication

Inmate Identify Confirmation

De-duplication
Matching 700K faces against 51M gallery (Florida DMV) found 5K duplicates
Where is Face Recognition Going?

Face recognition technology is moving towards **ubiquity**: reducing violent, unpredictable acts, like the rioting in London last summer.

Face Recognition and the London Riots

Widespread looting and rioting:

Extensive CCTV Network (1M CCTV cameras in London & 4M in U.K.):

Face recognition lead to many arrests:

Yet, many suspects still unable to be identified by COTS FRS:
Surveillance Plane to Circle Lancaster

16 Nov 2011

- Surveillance plane will hover Lancaster, CA for 10 hours a day collecting intelligence and keeping an eye on residents with a suite of video cameras and infrared sensors

http://www.homelandsecuritynewswire.com/surveillance-plane-circle-lancaster-ten-hours-day
FBI to Launch Nationwide Facial Recognition Service

• The FBI will activate a nationwide facial recognition service to allow local police to identify unknown subjects in photos

• Using the Next-Generation Identification system, law enforcement analysts will be able to upload a photo of an unknown person and, within 15 minutes, receive identified mug shots to inspect for potential matches; New surveillance system: 1 second to search through 36 million faces

Face Recognition for Social Networking

- SceneTap is a new service (website & app) that uses cameras in bars and clubs to detect male-female ratio, avg. patron age
- U.S. Senator Rockefeller recommending legislation to protect face privacy, cited SceneTap as an example

“Senator pushes for greater regulations on facial recognition tech”, Homeland Security Newswire. 9 November 2011
Overview of Automated Face Recognition Algorithms

- Most face recognition algorithms follow this pipeline
Appearance-based Methods

Input face

EigenFaces

Fisherfaces

Reconstructed face

PCA

LDA

Minimize reconstruction error
Maximize between-class to within-class scatter
Local Binary Patterns

How to Learn Salient Features?
Face Recognition Performance

- Controlled FR (FRGC)
  TAR of 99% @ FAR = 0.1%

- Frontal FR with lighting changes and expressions (MBGC)
  PittPatt: 84% TAR @ FAR = 0.1%

- Uncontrolled FR (free pose and occlusion)
  PittPatt: 43% TAR @ FAR = 0.1%

- FR in video surveillance

Who is this person at the “Occupy Wall Street” protest?
Unconstrained Face Recognition

Intra-class Variability

Facial Aging

Heterogeneous Face Recognition

30 y.o.  34 y.o.  41 y.o.  44 y.o.
Forensic Face Recognition

- Manual intervention: (i) preprocessing, (ii) examining the top-N retrieved faces from gallery

## Challenges in Forensic Face Recognition

<table>
<thead>
<tr>
<th></th>
<th>Pose</th>
<th>Illumination</th>
<th>Expression</th>
<th>Aging</th>
<th>Heterogeneous</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Non-forensic</strong></td>
<td></td>
<td></td>
<td></td>
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<td>Access control</td>
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</tr>
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<td>De-duplication</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Border control</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Forensic</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
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<td>Missing person</td>
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<td>✓</td>
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<td>✓</td>
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<tr>
<td>Surveillance</td>
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<td>✓</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Forensic sketch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>

- Non-forensic, fully automated scenarios do not encounter many of these performance degrading factors
- Forensic FR often requires a preprocessing stage of image enhancement or a specialized matcher to perform recognition
Matching Degraded Face Images

- Face images are often degraded during transition
- Given only a degraded face image, how can we improve its quality to make a successful hit?

Forensic Face Recognition Approaches

Preprocessing methods:

- Enhance the quality of a face image prior to submission to a face recognition system
- Compatible with the COTS FRS already in use

Forensic Face Recognition Approaches

Specialized face recognition systems:

– Designed to solve a specific matching task
– Any aspect of the face recognition process (e.g. representation, learning) can be modified
Applications within Forensics

• Heterogeneous Face Recognition
  – Sketch Recognition
• Face Aging
  – Synthesis (Preprocessing)
  – Feature-based discriminative (Specialized Matcher)
• Demographic-based Matcher
• Partial Face
• Face Mark
• FR at a Distance
Heterogeneous Face Recognition (HFR): Matching non-photograph face images (probe) to large gallery of frontal photos.
HFR using Kernel Prototypes

Method does not require direct similarity measure between modalities

Matching Sketches to Mug Shot Photos

• Forensic sketches used in most egregious crimes

• Ability to match these sketches to mug shot databases has strong benefits for safety and security

• Current FR technology is unable to perform this task

Earliest use of forensic sketch involved Jack the Ripper (late 1800’s)

<table>
<thead>
<tr>
<th>Method</th>
<th>Rank</th>
<th>FaceVACS</th>
<th>LFDA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>320</td>
<td>19.37</td>
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<td></td>
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<td>299</td>
<td>20.53</td>
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<td></td>
<td></td>
<td>2131</td>
<td>26.53</td>
</tr>
<tr>
<td></td>
<td></td>
<td>775</td>
<td>44.90</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1599</td>
<td>42.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1617</td>
<td>1617</td>
</tr>
</tbody>
</table>

Composite drawings of four of the suspects have been made based upon video images.
Facial Aging

- Aging-invariant FR algorithms
  - Learn invariant features
  - Synthesize appearances that offset facial variations over time

Accuracy of FR Systems vs. Time Lapse (TAR at FAR = 1.0%)

- Gallery seed
- Score=0.99
- Score=0.62
- Score=0.41
- Score=0.26

Time lapse in years:
- (0-1)
- (1-5)
- (5-10)
- (10+)

COTS 1
COTS 2
Approaches to Aging-Invariant FR

- Fusion of these two approaches offers the highest accuracy

Aging Recognition Examples

<table>
<thead>
<tr>
<th>Probe Images</th>
<th>Gallery Images</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age 51</td>
<td>Age 40</td>
<td>FaceVACs and generative model fail; discriminative approach succeeds</td>
</tr>
<tr>
<td>Age 42</td>
<td>Age 62</td>
<td>Discriminative approach fails; FaceVACs and generative model succeed</td>
</tr>
<tr>
<td>age 40</td>
<td>Age 55</td>
<td>All three methods fail; fusion of generative and discriminative models succeeds</td>
</tr>
<tr>
<td>Age 41</td>
<td>Age 34</td>
<td></td>
</tr>
<tr>
<td>Age 41</td>
<td>Age 62</td>
<td></td>
</tr>
</tbody>
</table>
Generalization of Aging-Invariant FR

- FR systems designed for aging have lower accuracy in non-aging scenarios.
- Implies need for multiple FR systems.

### Test set: 0 to 1 year time lapse

<table>
<thead>
<tr>
<th>Baselines:</th>
<th>MLBP Only</th>
<th>COTS1</th>
<th>COTS2</th>
</tr>
</thead>
<tbody>
<tr>
<td>RS-LDA trained on (time lapse in years):</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0-1)</td>
<td>94.1%</td>
<td>94.1%</td>
<td></td>
</tr>
<tr>
<td>(1-5)</td>
<td>93.1%</td>
<td>91.8%</td>
<td>94.1%</td>
</tr>
<tr>
<td>(5-10)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(10+)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(All)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- # of Match Comparisons: 19,996
- # of Non-Match Comparisons: 239,572,034

### Test set: 1 to 5 year time lapse

<table>
<thead>
<tr>
<th>Baselines:</th>
<th>MLBP Only</th>
<th>COTS1</th>
<th>COTS2</th>
</tr>
</thead>
<tbody>
<tr>
<td>RS-LDA trained on (time lapse in years):</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0-1)</td>
<td>90.3%</td>
<td>90.5%</td>
<td></td>
</tr>
<tr>
<td>(1-5)</td>
<td>89.1%</td>
<td>87.7%</td>
<td>90.2%</td>
</tr>
<tr>
<td>(5-10)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(10+)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(All)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- # of Match Comparisons: 33,443
- # of Non-Match Comparisons: 401,282,557

### Test set: 5 to 10 year time lapse

<table>
<thead>
<tr>
<th>Baselines:</th>
<th>MLBP Only</th>
<th>COTS1</th>
<th>COTS2</th>
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<tbody>
<tr>
<td>RS-LDA trained on (time lapse in years):</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>(0-1)</td>
<td>75.2%</td>
<td>81.2%</td>
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<tr>
<td>(1-5)</td>
<td></td>
<td>82.0%</td>
<td>81.3%</td>
</tr>
<tr>
<td>(5-10)</td>
<td></td>
<td>80.4%</td>
<td></td>
</tr>
<tr>
<td>(10+)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(All)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- # of Match Comparisons: 24,036
- # of Non-Match Comparisons: 215,795,208

### Face Recognition Across Demographics

<table>
<thead>
<tr>
<th>Age</th>
<th>Gender</th>
<th>Race/Ethnicity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young</td>
<td>Female</td>
<td>Black</td>
</tr>
<tr>
<td>Middle-Aged</td>
<td>Male</td>
<td>White</td>
</tr>
<tr>
<td>Old</td>
<td>Female</td>
<td>Hispanic</td>
</tr>
</tbody>
</table>

- Are FR algorithms biased towards or against certain demographic prototypes?
Dynamic Face Matcher Selection

- Ability to improve performance on race and age suggests dynamic face matcher selection

Dynamic Face Matcher Selection Example

<table>
<thead>
<tr>
<th>Probe Images:</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Probe Image 1" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gallery Mates:</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image10" alt="Gallery Image 1" /></td>
</tr>
</tbody>
</table>

**Retrieval Rank for 4SF Trained on all cohorts equally:**

<table>
<thead>
<tr>
<th>Rank</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>873</td>
<td></td>
</tr>
<tr>
<td>866</td>
<td></td>
</tr>
<tr>
<td>763</td>
<td></td>
</tr>
<tr>
<td>679</td>
<td></td>
</tr>
<tr>
<td>628</td>
<td></td>
</tr>
<tr>
<td>608</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

**Retrieval Rank for 4SF Trained on White cohort exclusively:**

<table>
<thead>
<tr>
<th>Rank</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td></td>
</tr>
<tr>
<td>42</td>
<td></td>
</tr>
<tr>
<td>48</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td></td>
</tr>
<tr>
<td>48</td>
<td></td>
</tr>
<tr>
<td>42</td>
<td></td>
</tr>
</tbody>
</table>
Dynamic Face Matcher Selection Example

Probe Images:

Gallery Mates:

Retrieval Rank for 4SF Trained on all cohorts equally:

| Rank | 820 | 811 | 730 | 640 | 574 | 547 | 7 | 6 |

Retrieval Rank for 4SF Trained on Black cohort exclusively:

| Rank | 20  | 34  | 43  | 9   | 43  | 18  | 42 | 41 |
Facial Marks

- Facial marks can be useful to filter gallery (from even verbal query), and generate a small set of candidate face images.

Face Finder

• Query based on:
  • Face marks, Date of birth, Date of arrest, Gender, Ethnicity, Height, Weight

Detroit police linked at least six armed robberies at an ATM after matching a tipster’s description of the suspect’s distinctive tattoos.
A Tattoo Revealed True Identity

This person gave his name as “Darnell Lewis” to an officer, but the officer noticed the man had “Frazier” tattooed on his neck, his real surname. He was arrested on four misdemeanor warrants. (Dec. 2008, St. Paul.)
Identical Twins, One Charged in a Fatal Shooting, Create Confusion for the Police

By MARC LACEY
Published: August 8, 2011

CHANDLER, Ariz. — At first, the murder case against Orlando Nembhard seemed solid, as witness after witness came forward to say they saw someone that looked just like him brandish a pistol in February outside a

Pairs of identical twins:

Facial marks (e.g. moles) can help distinguish identical twin pairs

Face Recognition at a Distance

Visible still images and NIR images up to a distance of 200m

Sky-Watcher SK MAK 180 telescope (focal length of 2700mm)

Near-infrared illuminator

## Daytime Images

<table>
<thead>
<tr>
<th></th>
<th>1m</th>
<th>50m</th>
<th>100m</th>
<th>150m</th>
<th>200m</th>
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</thead>
<tbody>
<tr>
<td>IPD</td>
<td>525</td>
<td>174</td>
<td>103</td>
<td>72</td>
<td>54</td>
</tr>
<tr>
<td>SCORE</td>
<td>-</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>0.999</td>
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<tr>
<td>IPD</td>
<td>540</td>
<td>172</td>
<td>104</td>
<td>70</td>
<td>55</td>
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<tr>
<td>SCORE</td>
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<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
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<tr>
<td>IPD</td>
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<td>187</td>
<td>114</td>
<td>73</td>
<td>56</td>
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<tr>
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<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
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</tbody>
</table>
Nighttime Images

<table>
<thead>
<tr>
<th>Distance</th>
<th>1m</th>
<th>50m</th>
<th>100m</th>
<th>150m</th>
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</thead>
<tbody>
<tr>
<td>IPD</td>
<td>525</td>
<td>460</td>
<td>272</td>
<td></td>
</tr>
<tr>
<td>SCORE</td>
<td>-</td>
<td>0.126</td>
<td>0.401</td>
<td></td>
</tr>
<tr>
<td>IPD</td>
<td>525</td>
<td>471</td>
<td>286</td>
<td>159</td>
</tr>
<tr>
<td>SCORE</td>
<td>-</td>
<td>0.530</td>
<td>0.033</td>
<td>0.000</td>
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<tr>
<td>IPD</td>
<td>525</td>
<td>471</td>
<td>286</td>
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</tr>
<tr>
<td>SCORE</td>
<td>-</td>
<td>0.186</td>
<td>0.223</td>
<td></td>
</tr>
</tbody>
</table>
Caricature Recognition

- Humans recognize caricature sketches more easily than realistic sketches
- Studying **caricatures** may lead to improved face representations

Studies in Cognitive Science

- Despite extreme exaggeration of facial features, people may be better at recognizing caricature than veridical portrait [Mauro & Kubovy]
- Caricature can be considered as an extrapolation in “face space”

Caricature Recognition

**Encode as Qualitative Features**

**Histogram Representation**

**Difference Vector**

**Classifier**

**Fusion**

**Similarity Score**

**Method** | **TAR @ FAR=10.0%** | **TAR @ FAR=1.0%** | **Rank-1** | **Rank-10**
---|---|---|---|---

**Qualitative Features (no learning):**

- $NN_{L2}$
  
  - TAR @ FAR=10.0%: $39.2 \pm 5.4$
  - TAR @ FAR=1.0%: $9.4 \pm 2.7$
  - Rank-1: $12.1 \pm 5.2$
  - Rank-10: $52.1 \pm 7.1$

**Qualitative Features (learning):**

- Logistic Regression
  
  - TAR @ FAR=10.0%: $50.3 \pm 2.4$
  - TAR @ FAR=1.0%: $11.3 \pm 2.9$
  - Rank-1: $17.7 \pm 4.2$
  - Rank-10: $62.1 \pm 3.8$

- MKL
  
  - TAR @ FAR=10.0%: $39.5 \pm 3.2$
  - TAR @ FAR=1.0%: $7.4 \pm 3.9$
  - Rank-1: $11.0 \pm 3.9$
  - Rank-10: $50.5 \pm 4.0$

- $NN_{MKL}$
  
  - TAR @ FAR=10.0%: $46.6 \pm 3.9$
  - TAR @ FAR=1.0%: $10.3 \pm 3.6$
  - Rank-1: $14.4 \pm 2.9$
  - Rank-10: $59.5 \pm 3.9$

- SVM
  
  - TAR @ FAR=10.0%: $52.6 \pm 5.0$
  - TAR @ FAR=1.0%: $12.1 \pm 2.8$
  - Rank-1: $20.8 \pm 5.6$
  - Rank-10: $65.0 \pm 3.8$

- Logistic Regression+$NN_{MKL}$+SVM
  
  - TAR @ FAR=10.0%: $56.9 \pm 3.0$
  - TAR @ FAR=1.0%: $15.5 \pm 4.6$
  - Rank-1: $23.7 \pm 3.5$
  - Rank-10: $70.5 \pm 4.4$

**Image Descriptors (learning):**

- LBP with LDA
  
  - TAR @ FAR=10.0%: $33.4 \pm 3.9$
  - TAR @ FAR=1.0%: $11.5 \pm 2.5$
  - Rank-1: $15.5 \pm 4.6$
  - Rank-10: $42.6 \pm 4.6$

**Qualitative Features + Image Descriptors:**

- Logistic Regression+$NN_{MKL}$+SVM+LBP with LDA
  
  - TAR @ FAR=10.0%: $61.9 \pm 4.5$
  - TAR @ FAR=1.0%: $22.7 \pm 3.5$
  - Rank-1: $32.3 \pm 5.1$
  - Rank-10: $74.8 \pm 3.4$

200 pairs
Partial Face Recognition

- Occlusions by other objects
- Pose (self occlusion)
- Facial accessories: hat, sunglasses, scarf, mask
- Limited field of view
Summary

• Requirements in forensic face recognition are paving the way for research in unconstrained face recognition

• Many challenges in using low quality video data to ascertain an identity

• In most difficult and critical circumstances, human analysts can intervene to improve recognition accuracy
Summary

- Eventually galleries will span the entire population
- Safety and security can be greatly improved by leveraging large face databases

Source: http://www.planetbiometrics.com/
CAN I BUY YOU A DRINK?

BEEP
BEEP
BEEP

3D optical scan in progress.......... initiating face recognition.......... querying central database.......... identity match found......................

UTF ?

USER RATING:
★ ★ ★ ★ ★

USER COMMENTS:
"emotionally inaccessible"
"selfish in bed"
"womanizing, lying cheater"

* PAT. PEND.,