# Biometric Recognition: How Do I Know Who You Are?

Anil K. Jain

Michigan State University

http://biometrics.cse.msu.edu

April 2, 2010

# Invasion of Body Scanners

1,800 will be installed by 2014 at a cost of ~$3B; GAO now questions their effectiveness (3/18/10)


http://aftermathnews.wordpress.com/2009/10/18/naked-airport-scanners-in-child-porn-uproar/

# Security Threats

We now live in a global society of increasingly desperate and dangerous people who can not be trusted based on identification documents

- Are the credentials genuine?
- Are the credentials in the possession of authorized persons?

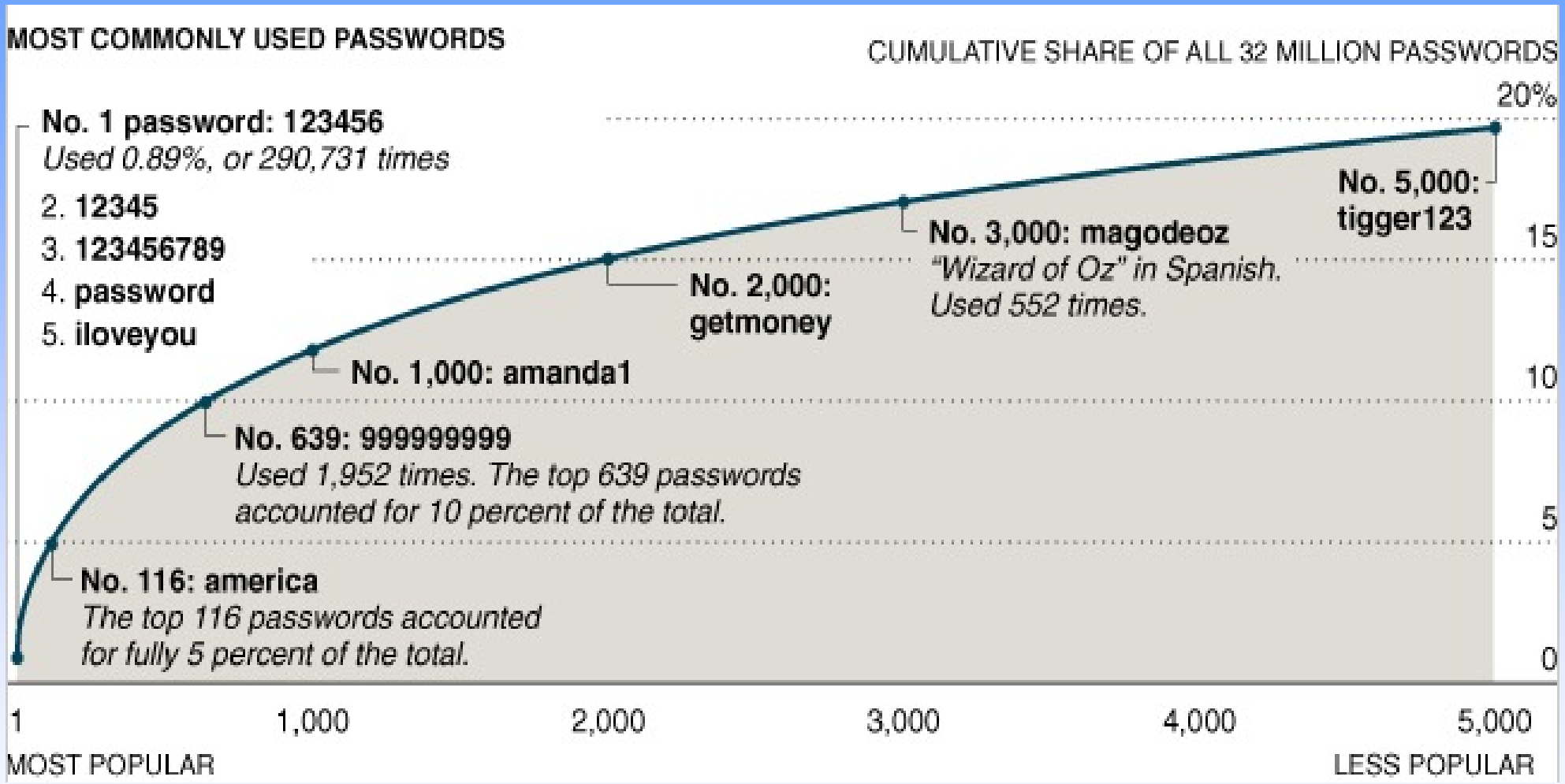
Security: Homeland, corporate & individual

# Al-Qaida Gets Fake Papers


- 290,000 passports issued by UK were lost/stolen in 2006
- Al-Qaida terrorist captured in Britain had 7 passports in his true identity and 2 passports in fraudulent identities
- U.K. accuses Israel of falsifying British passport (WSJ, March 24, 2010)

http://press.homeoffce.gov.uk/press-releases/passport-warning?version=1

# The Risk of Keeping It Simple!




The New York Times, January 21, 2010

32 million passwords and e-mail addresses were stolen from RockYou! 6.4 million accounts used only 5000 different passwords!

# Phishing Attacks

- Users easily divulge their ID & passwords
- Identity theft: ~10 million victims in 2008

# Biometric Recognition

- Recognize a person by his body traits & link that body to an externally assigned identity
- Traits are claimed to be unique & permanent


Biometric passport

http://news.bbc.co.uk/1/shared/spl/hi/guides/456900/456993/html/default.stm

Cashless payment system, Todholm primary school (Courtesy: Fujitsu)

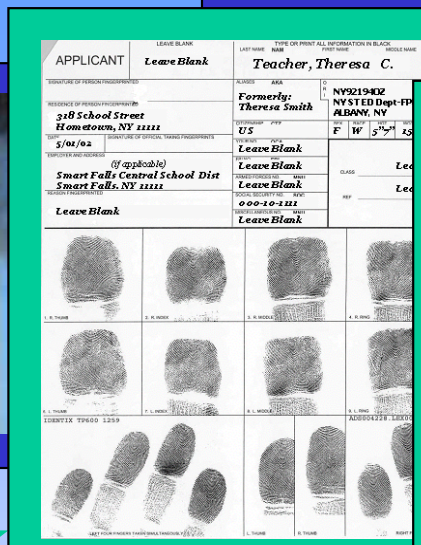
# Why Biometrics?

- Discourages fraud
- Enhances security
- Not susceptible to forgery or theft
- Eliminates repudiation claims
- Imparts convenience to users


ATM (card + PIN)


ATM (card + PIN + iris)

# Biometric Milestones




Fi… p… Gal… Habi… Crimina…

300 B.C. | 1839 | 1869 | 1883 | 1900 | …2008

A Chinese deed o… of sale with a … fingerprint B…

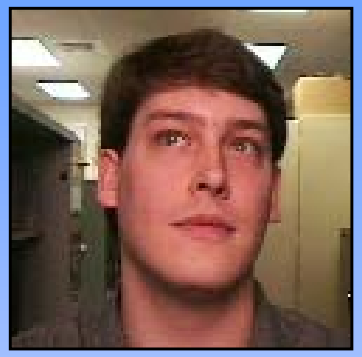
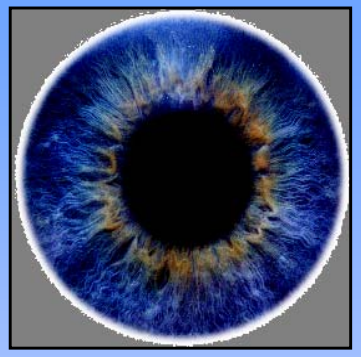
State Al…

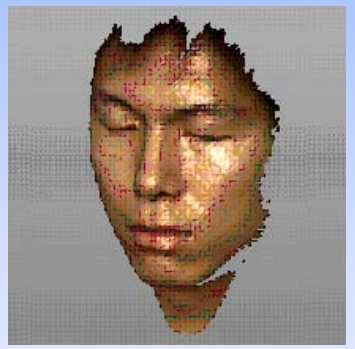
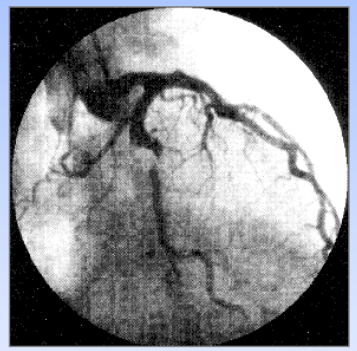
Criminal Booking

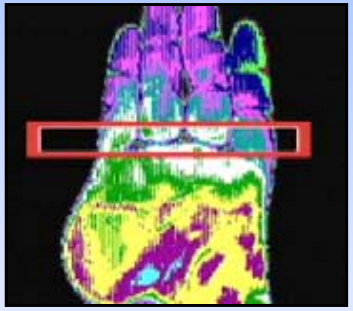
Courtesy: John D. Woodward, RAND Corporation

# Biometric Traits

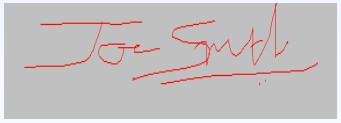
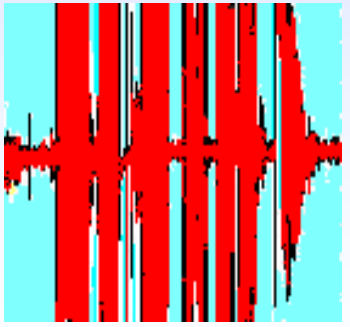





DNA matching is not yet real-time

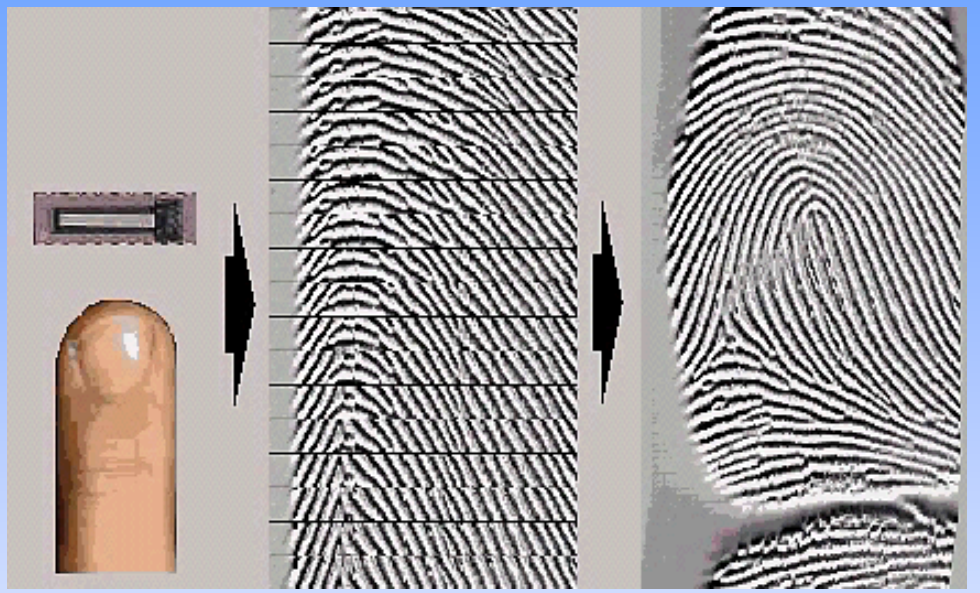
# Best Biometric Trait!

- **Universality** (everyone has this trait)
- **Uniqueness** (everyone has a different value)
- **Permanence** (does not change over time)
- **Collectability** (easy to measure)
- **Performance** (recognition accuracy, cost)
- **Acceptability** (are users willing to accept it?)
- **Circumvention** (how easily can it be spoofed?)

Choice of a biometric trait depends on application

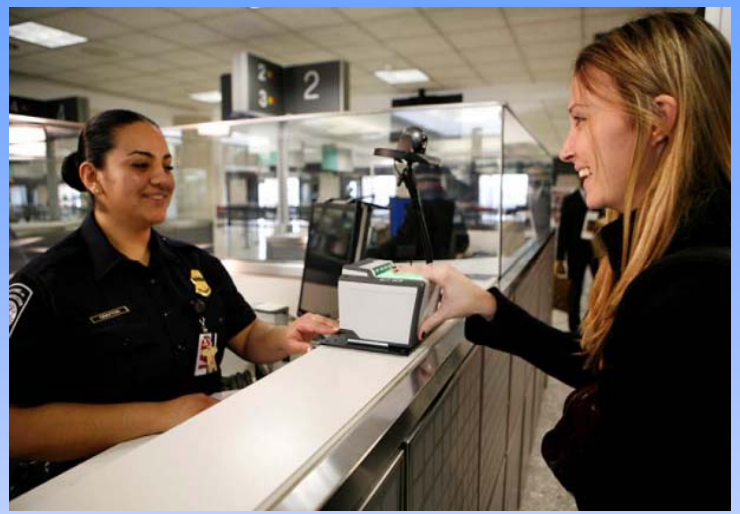
# Biometrics: New Era

- Border security
- Multiple enrollment
- Financial fraud
- User convenience



- Cheap & compact sensors
- Embedded systems

# Homeland Security



US-VISIT


UAE border crossing

Australia's SmartGate


Hong Kong smart ID card

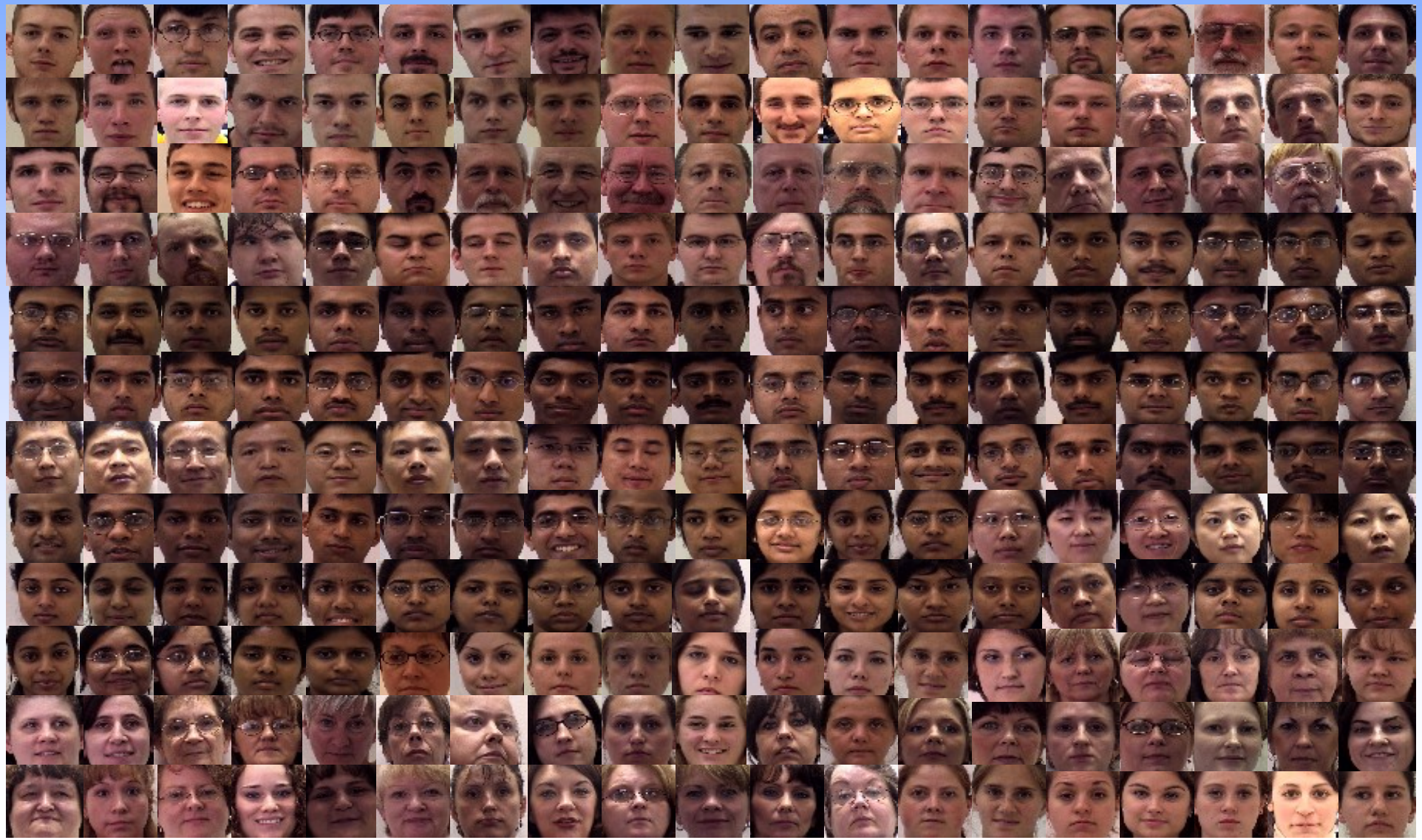
# Biometrics in Afghanistan

Courtesy: http://online.wsj.com/article/SB125910374196463061.html

U.S. forces use Handheld Interagency Identity Detection Equipment (HIIDE) devices during neighborhood patrols to find insurgents

# Duplicate Driver Licenses

Florida DMV found ~5,000 duplicates by matching 700K face images against a database of 51M faces



# Disney World, Orlando

200K visitors per day, 365 days per year

# Applications

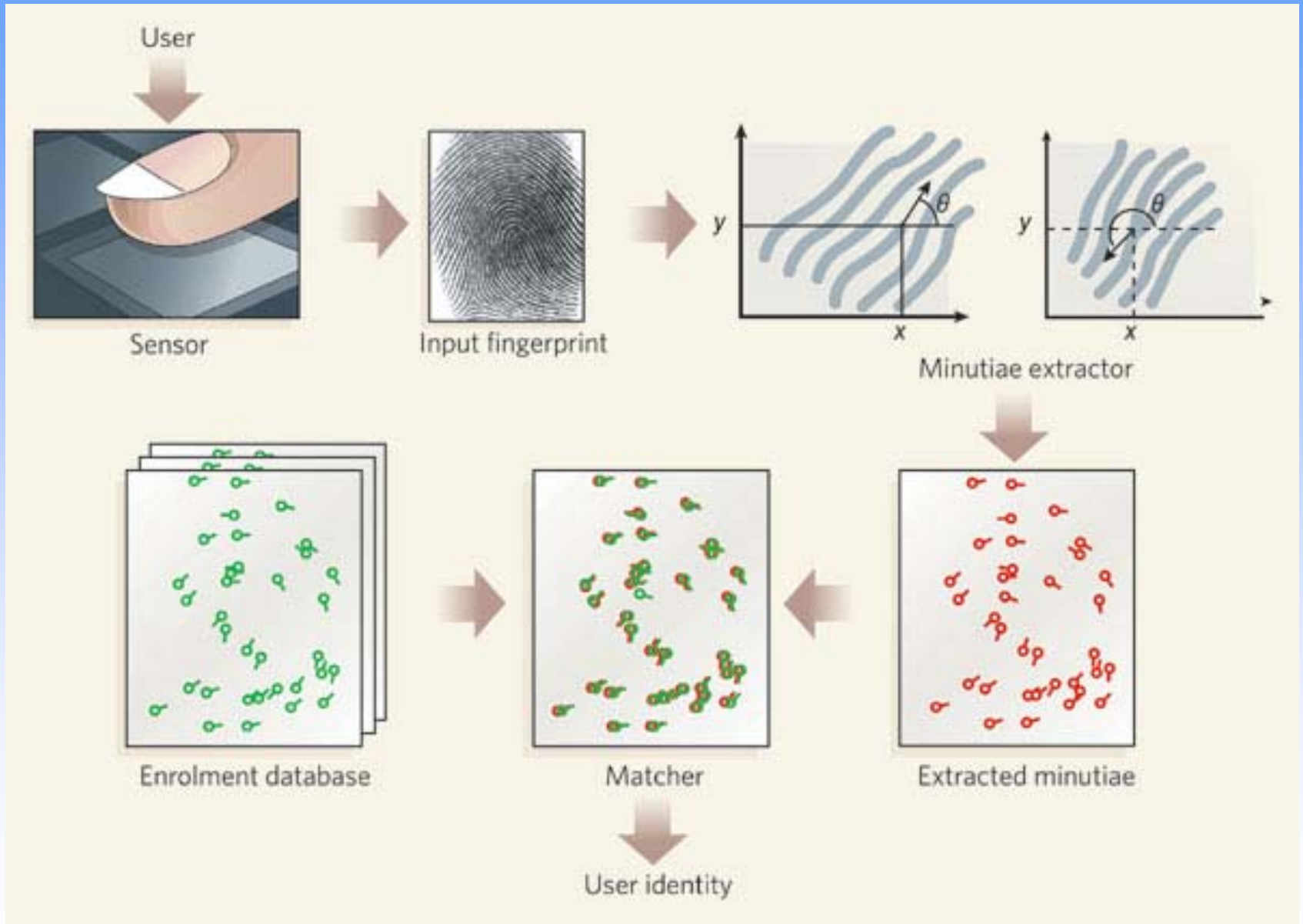

Meijer supermarket, Okemos

Time & Attendance


Citibank, Singapore: pay by fingerprints

User Profiling

# Biometric Recognition System




Enrollment vs. Recognition

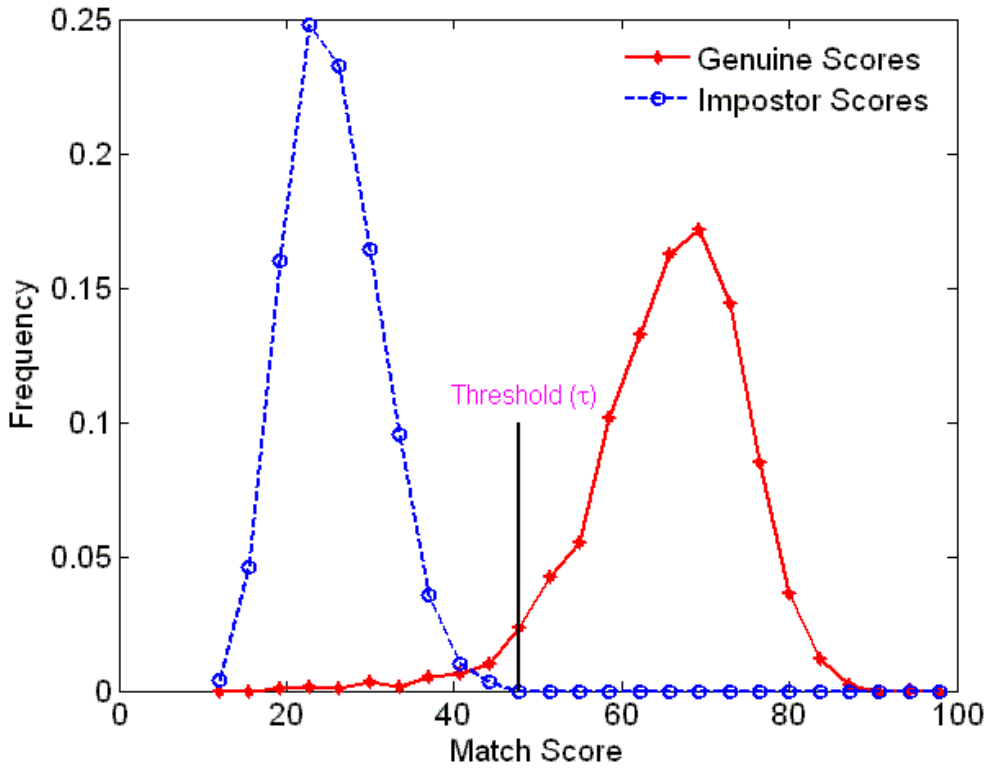
# Fingerprint Matching

Original Images

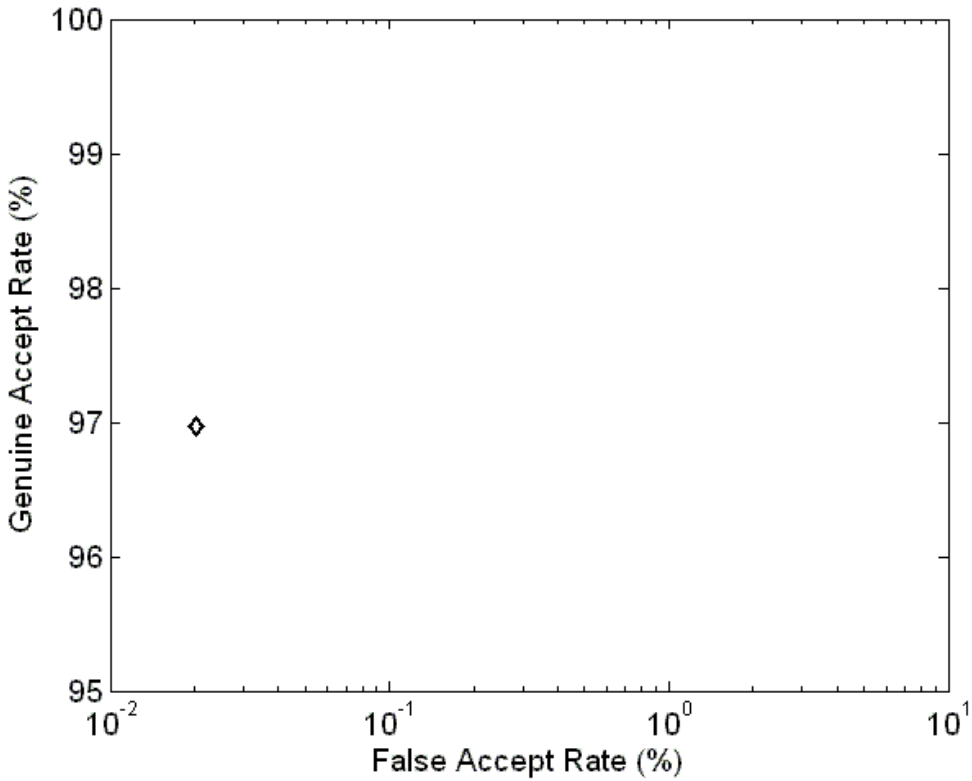
Template

Query

# Match Score




Match Score Distribution



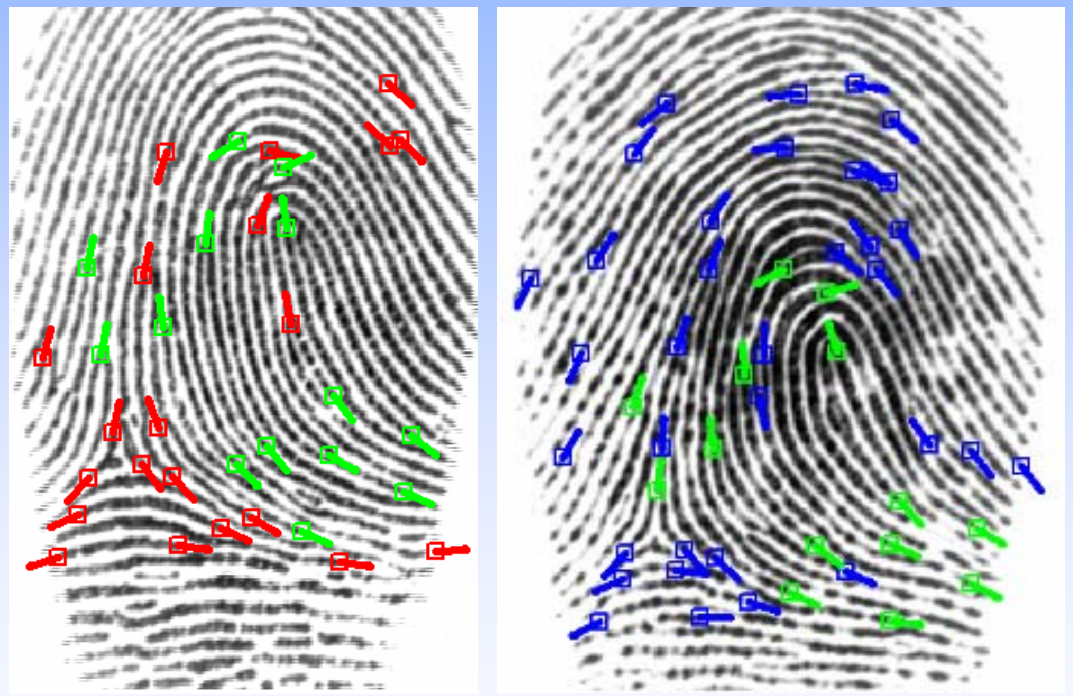

ROC Curve

False Accept vs. False Reject

# Matching Errors

- Noise & distortion
- Small overlap between template & query

False Reject



False Accept

# State-of-the-art Error Rates

| | Test | Test Parameter | False Reject Rate | False Accept Rate |
|---|---|---|---|---|
| Fingerprint | FpVTE [2003] | US govt. operational data | 0.6% | 0.1% |
| Face | FRGC [2006] | Time lapse, varied lighting/expression, outdoor/indoor | 1% | 0.1% |
| Iris | ICE [2006] | Controlled Illumination, broad quality range | 1.1-1.4% | 0.1% |
| Voice | NIST [2008] | Text independent, multi-lingual | 12% | 0.1% |

Performance depends on test population, sensor & test environment

# Large Scale Civil Identification

- 500 million citizens of India have no definitive identity, excluding them from social, political & economic life
- Unique ID Authority of India plans to issue biometrics-based documents robust to duplication & forgery
- How to ensure accuracy for 1 billion identities?

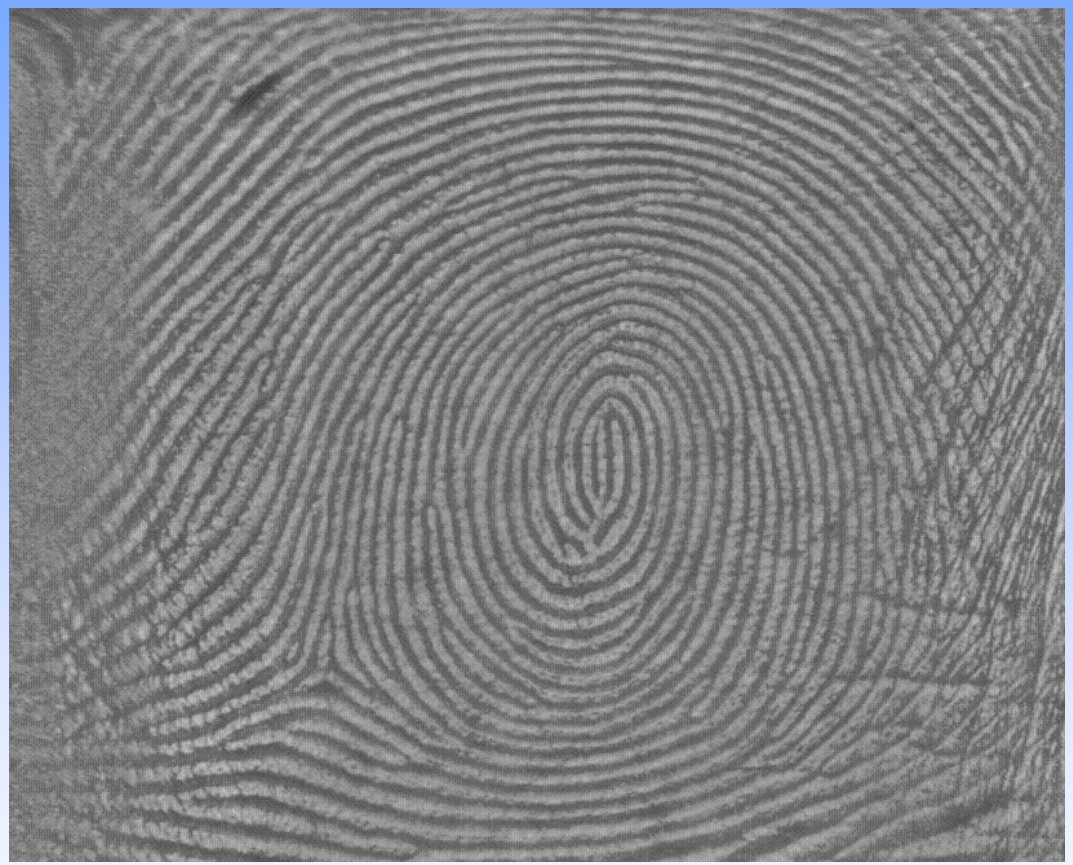
Bank in Malawi uses fingerprints for micro-loans

# Some Challenges

- Better sensors
- Matching latent fingerprints
- Fusion
- Robust Face recognition
- Surveillance
- Soft biometrics
- Template security

# 3D Touchless Imaging

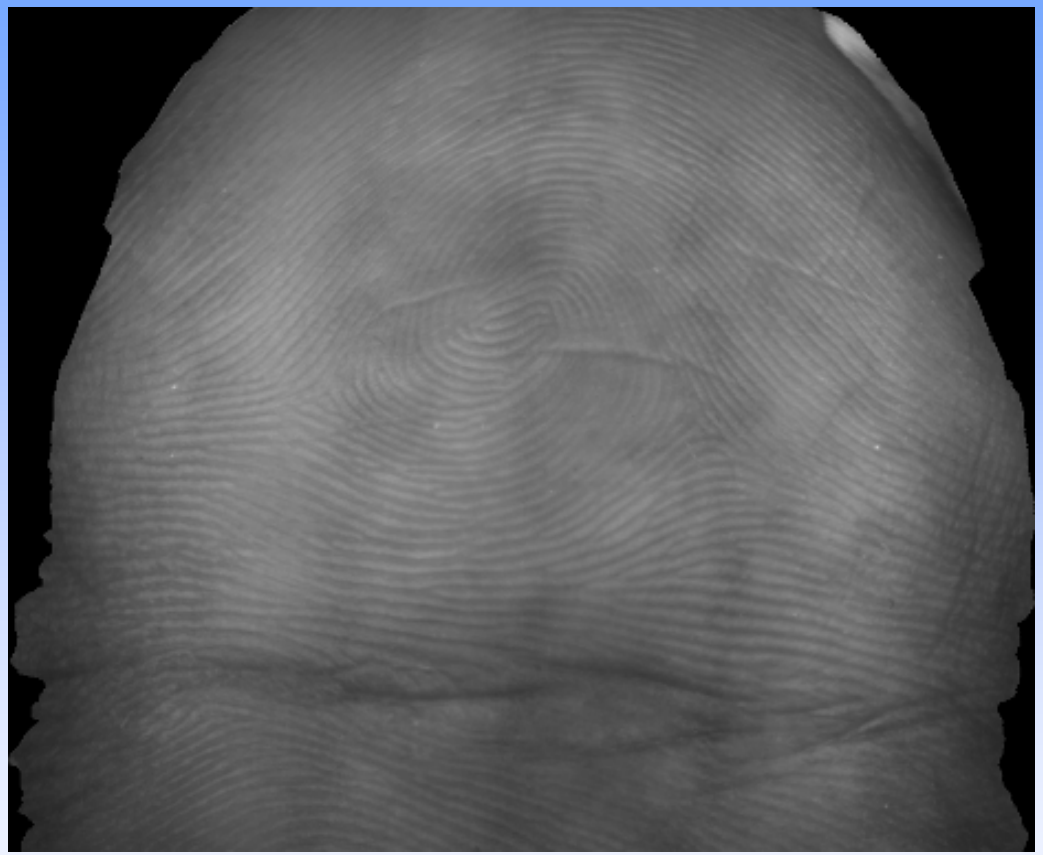
Touchless 3D image



Touchless “rolled” image

Courtesy: TBS North America

# Touchless Fingerprint Imaging



Touchless “rolled” image

Live-scan rolled image

## Sensor Interoperability

.

# Latent Fingerprint Matching

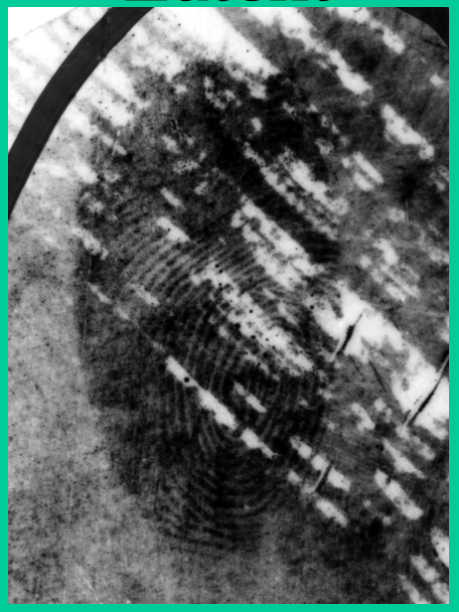
## Rolled

- “Nail-to-nail”
- Large area
- Skin distortion

## Plain

- Pressed on a flat surface
- Small area
- Less distortion

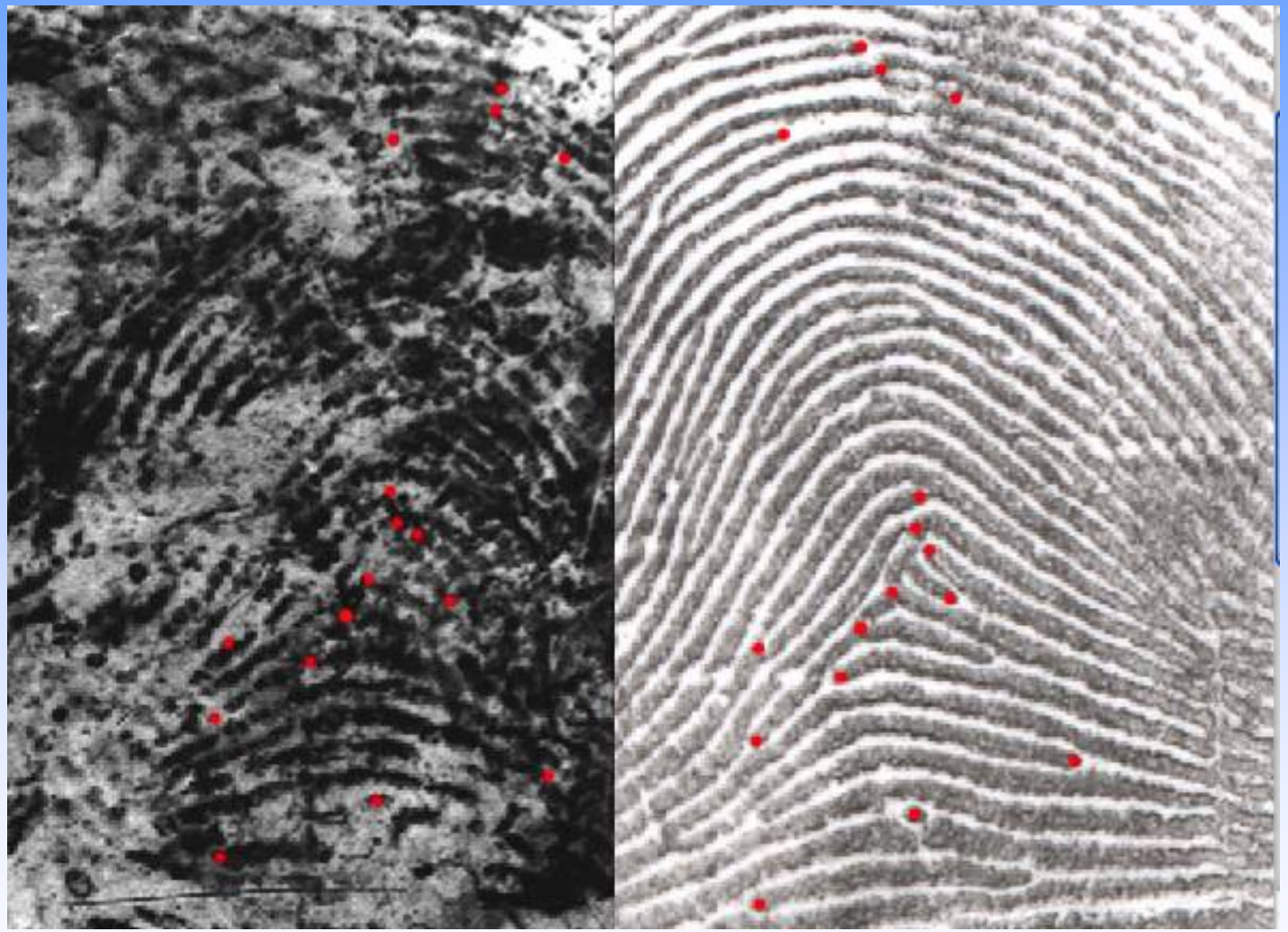
## Latent



- Lifted from crime scenes
- Poor quality
- Partial prints

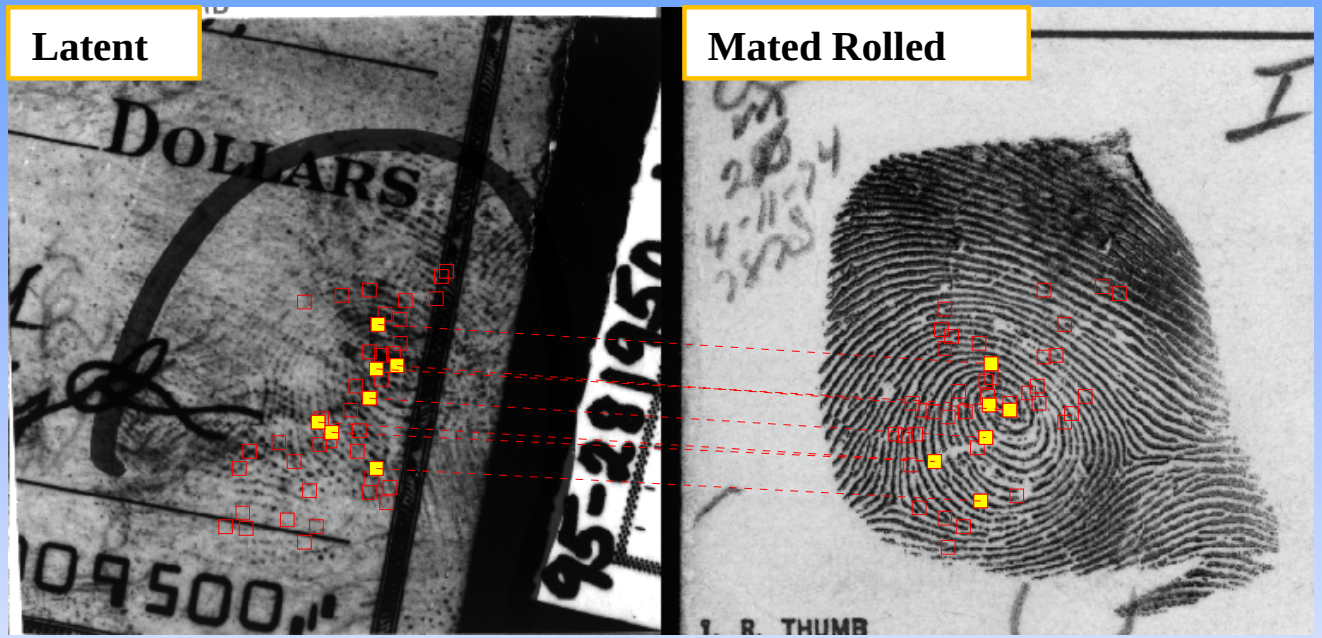
- Rolled to Rolled matching
- Latent to Rolled matching
- Rolled to Latent matching

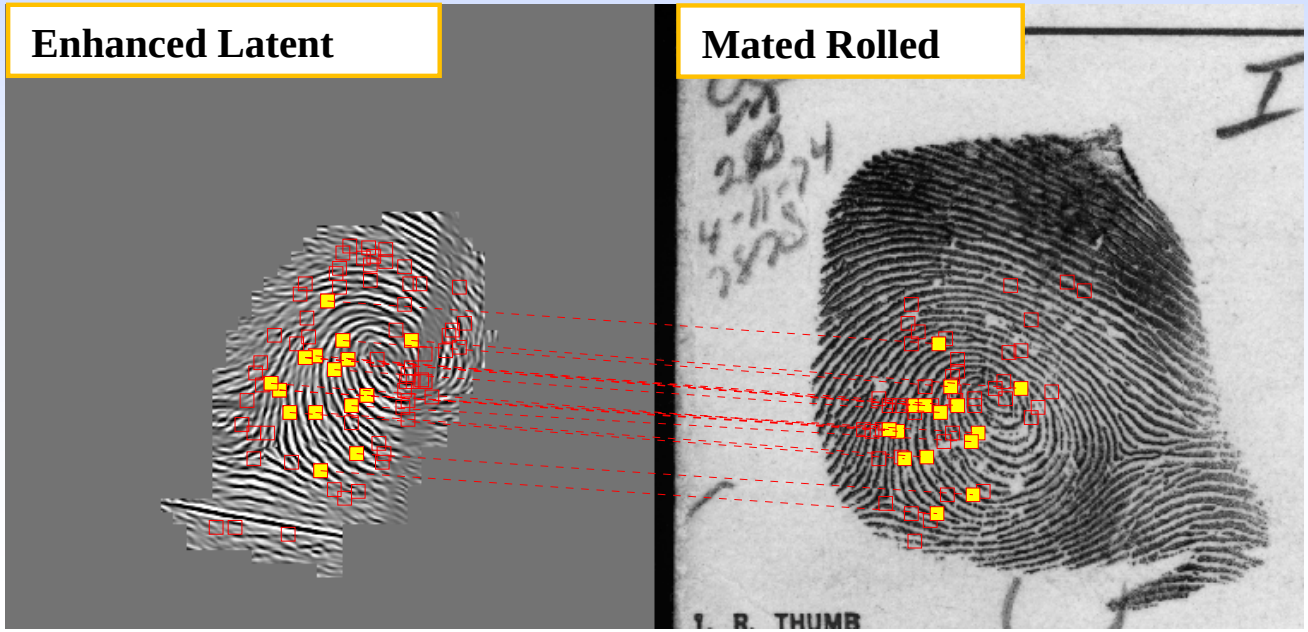
# Latent Matching Errors



FBI matched Mayfield's fingerprints with those found on a bag at the bombing site in Madrid. He was later released after Spanish law enforcement officials said they had matched fingerprints on the plastic bag to an Algerian man

# Latent Enhancement



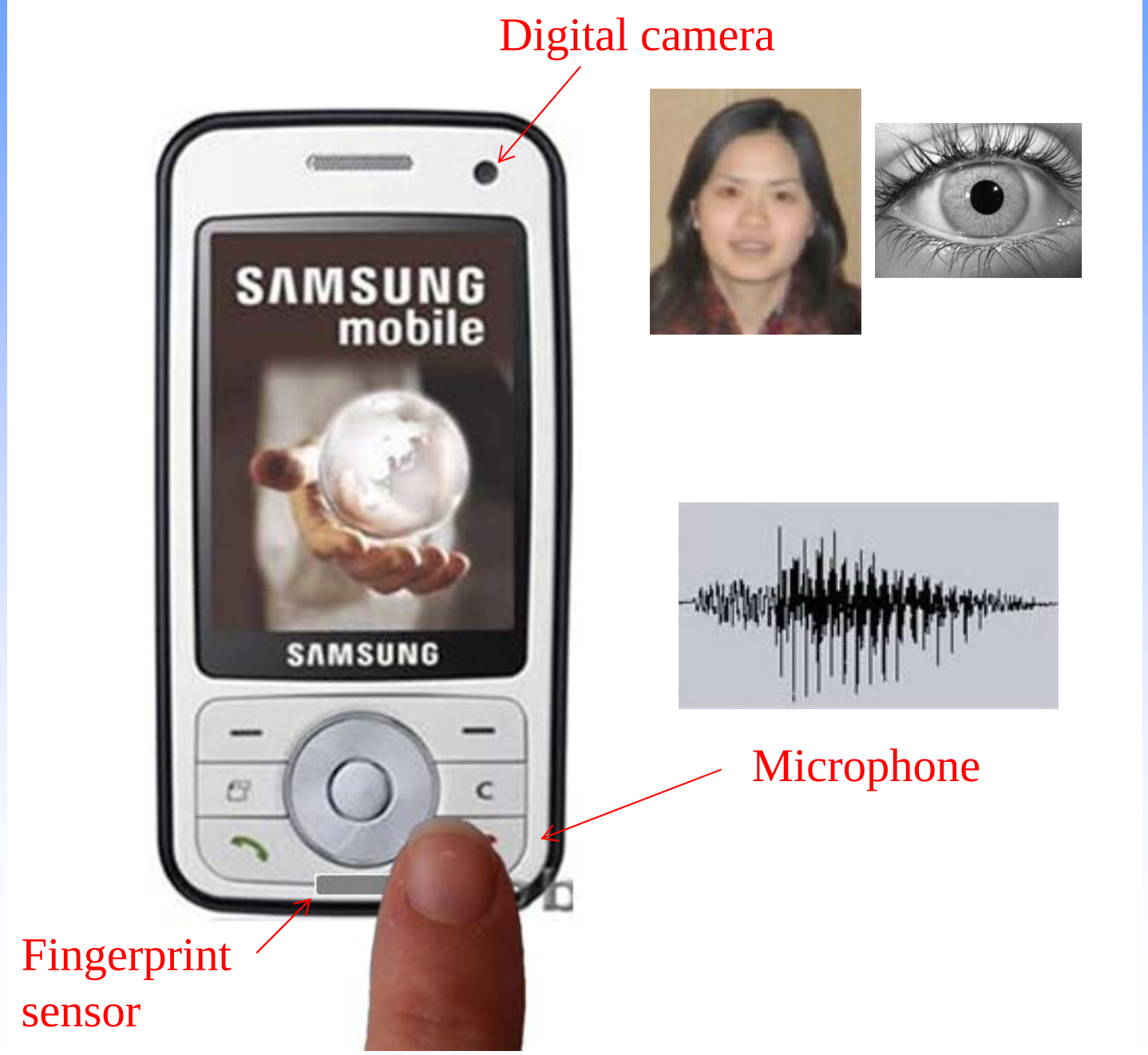




# Matched Minutiae: 7
Matching Score: 4
Rank: 309

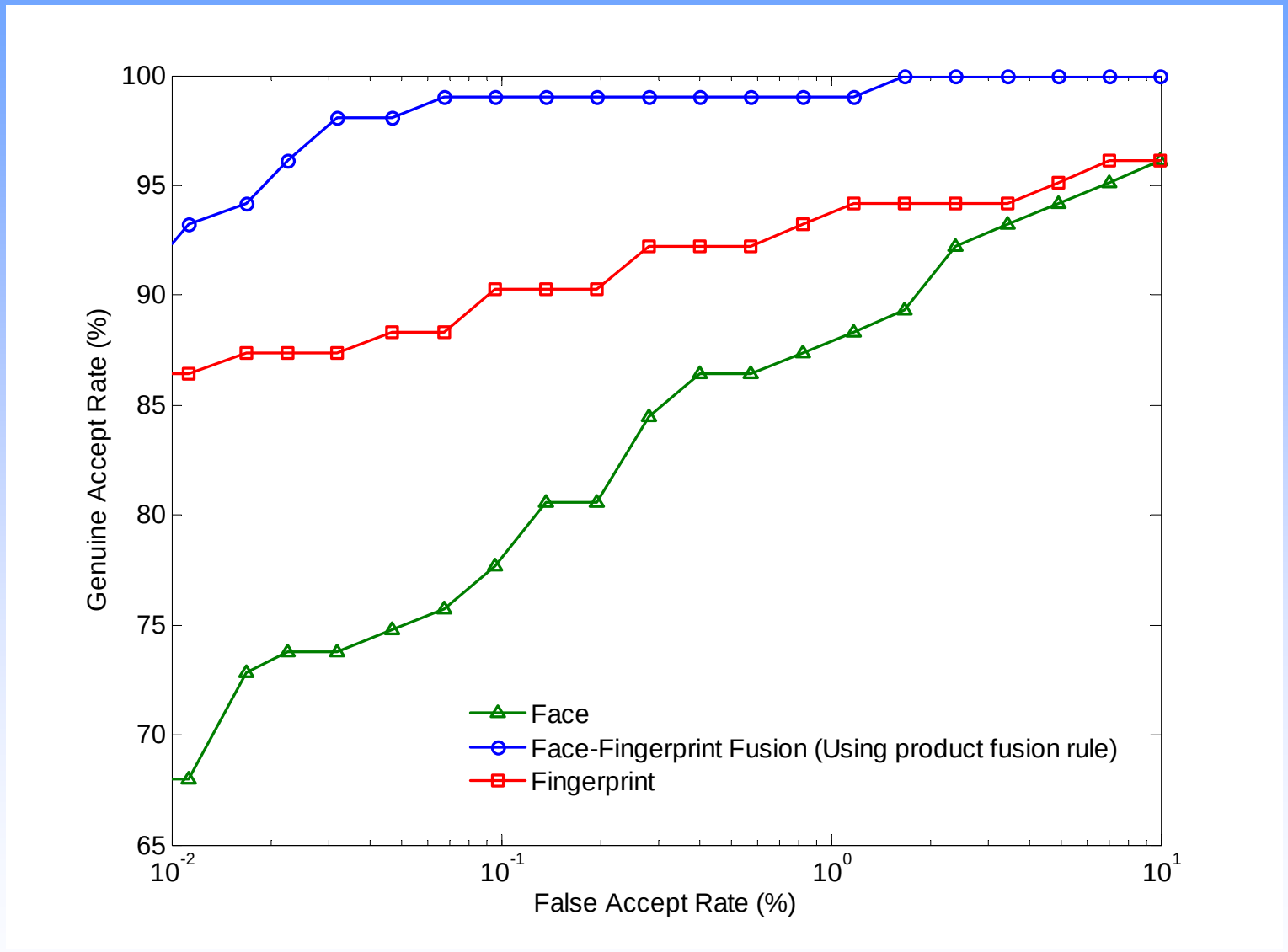
# Matched Minutiae: **17**
Matching Score: **47**
Rank: **1**

Minutiae matcher:
VeriFinger SDK 4.2

# Multimodal Biometrics

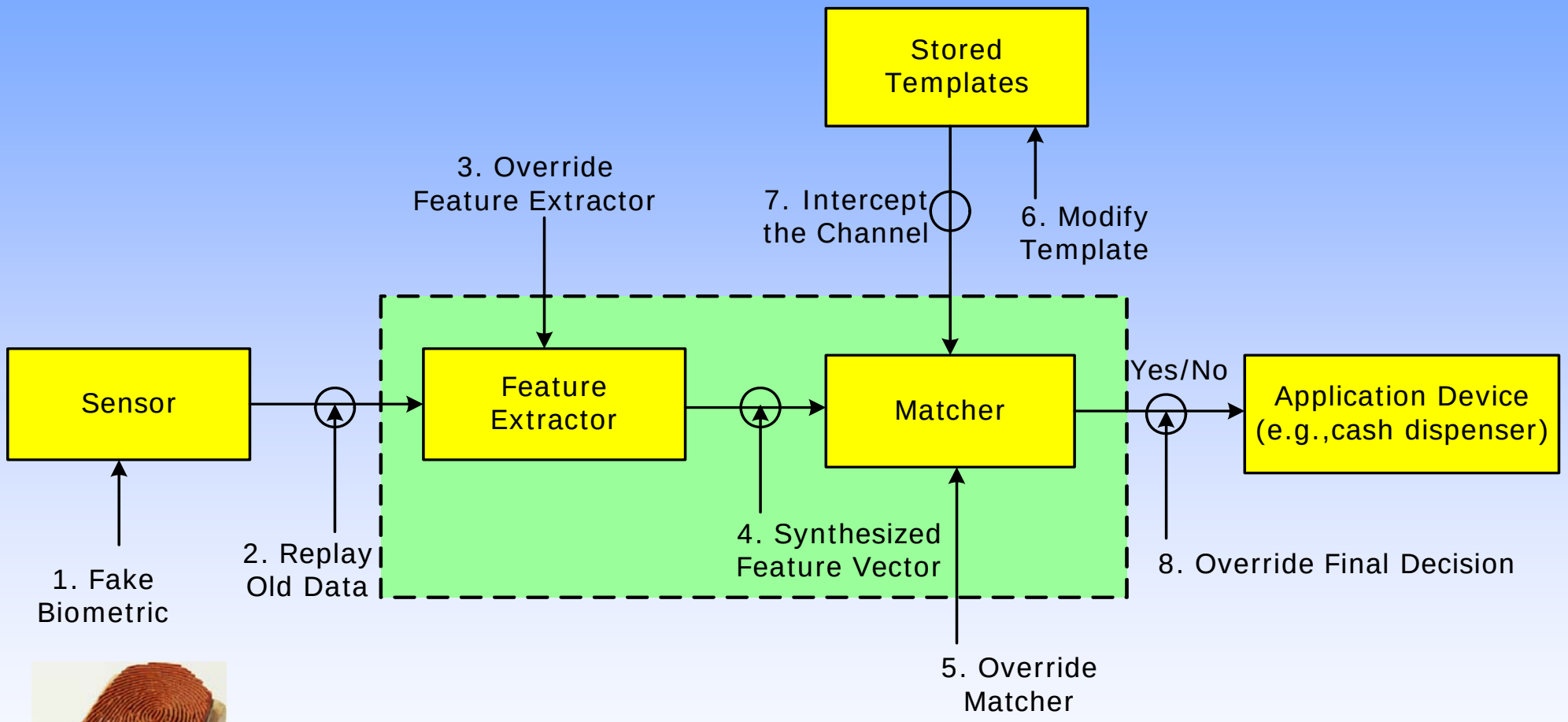


# Fusion of Fingerprint & Face




NIST BSSR1 database; 517 users

# Adversary Attacks

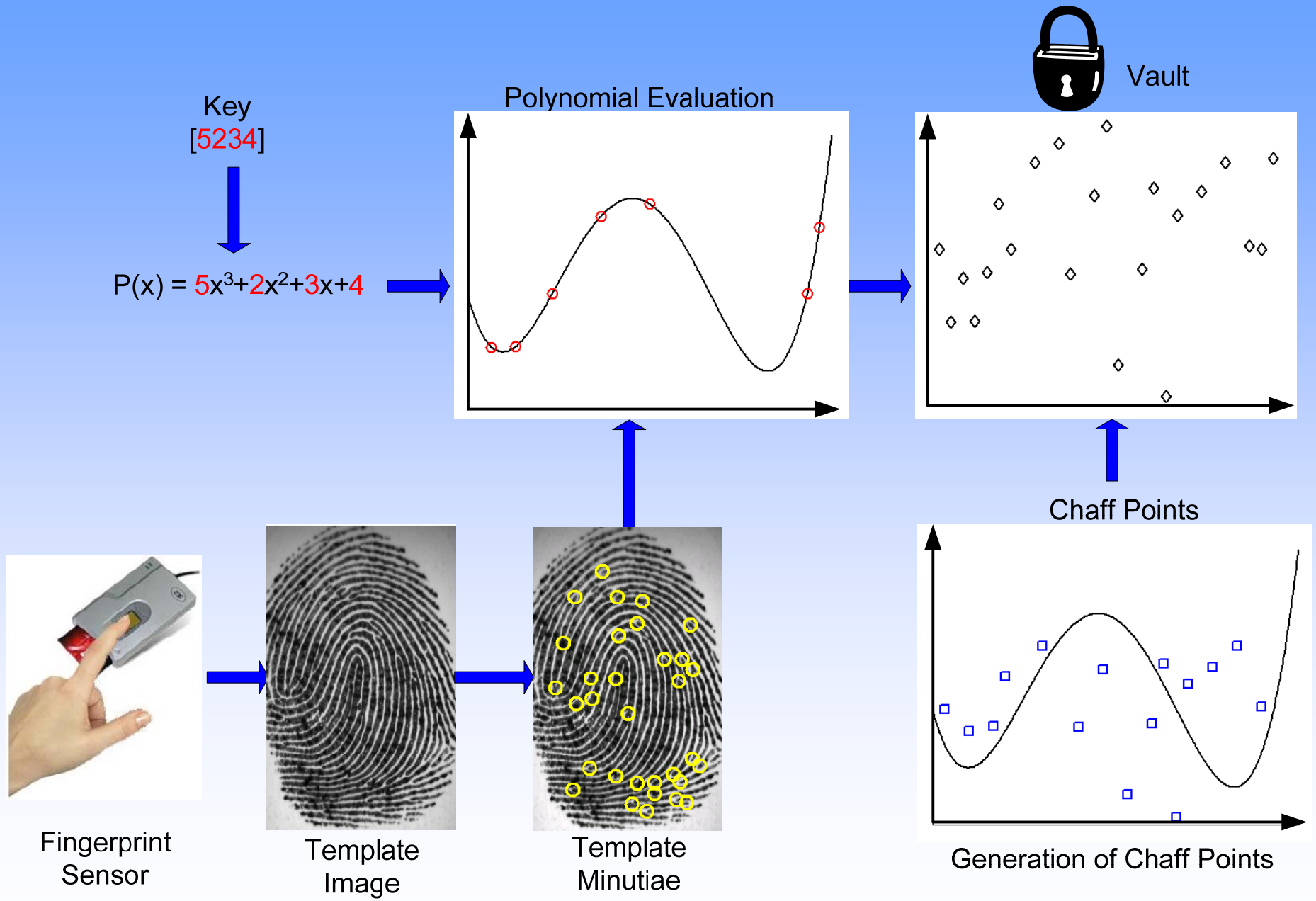



# Template Protection

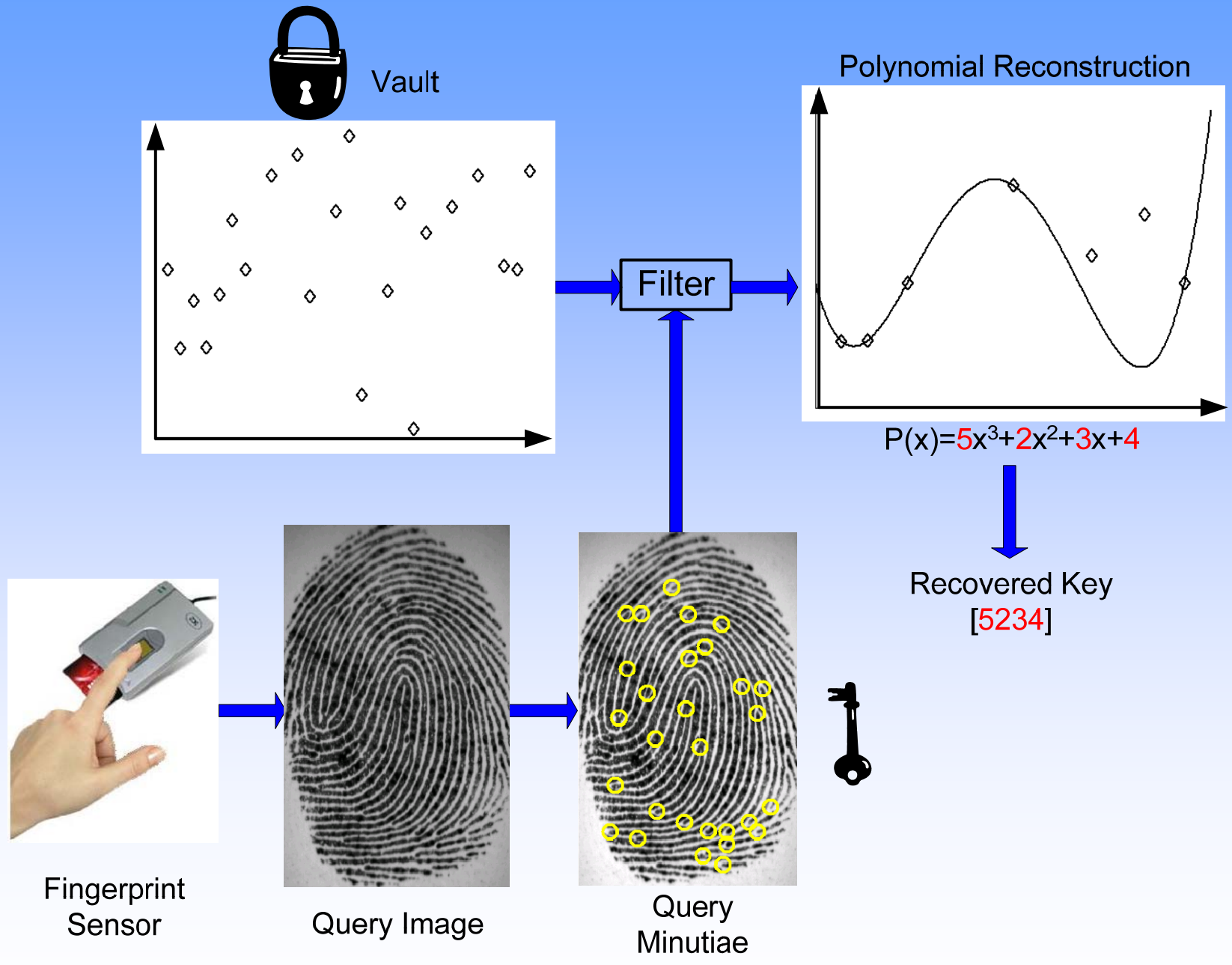
- Can a fingerprint similar to original fingerprint be reconstructed from minutiae template?


Match score between original & reconstructed image = 63; threshold @ FAR of 0.000001 is 38

# Fingerprint Fuzzy Vault: Encoding



# Fingerprint Fuzzy Vault: Decoding




Recovery of a valid key indicates successful match

# Fingerprint Alteration

- Asylum-seekers to EU were found to have cut or burnt their fingertips to evade identification
- Korean women arrested in Japan for illegal entry

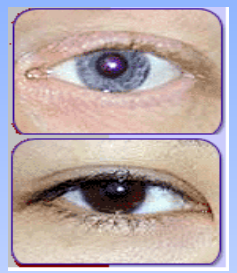
http://www.dailymail.co.uk/news/worldnews/article-1201126/Calais-migrants-mutilate-fingertips-hide-true-identity.html#
http://news.bbc.co.uk/2/hi/europe/3593895.stm

# Soft Biometrics

They provide some discriminatory information & can be used in conjunction with primary biometric traits

Ethnicity, Skin Color, Hair color

Height



Eye color

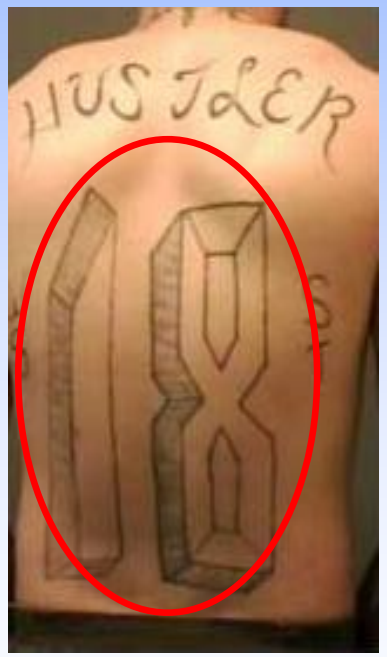
Scars

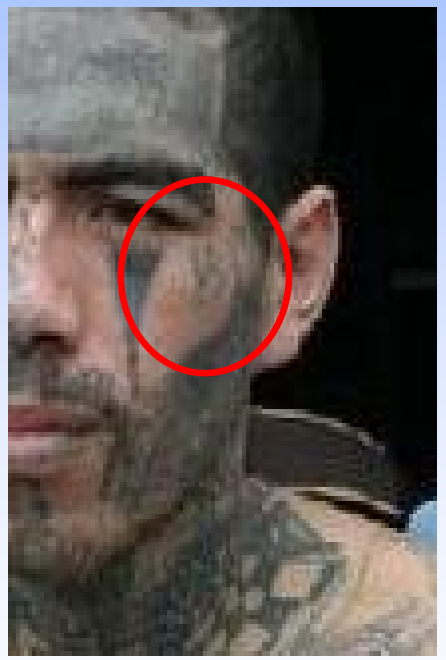
Marks

Tattoos

# Tattoos for Victim & Suspect Identification

- About 800,000 gang members on the streets nationwide; 100,000 in greater LA area
- 18th Street gang with ~15,000 members is one of the largest LA-based street gang





18th St. Gang tattoo: they sport the number "18" in a very visible and obvious manner

# Tattoos as Soft Biometric

# Content-based Image Retrieval

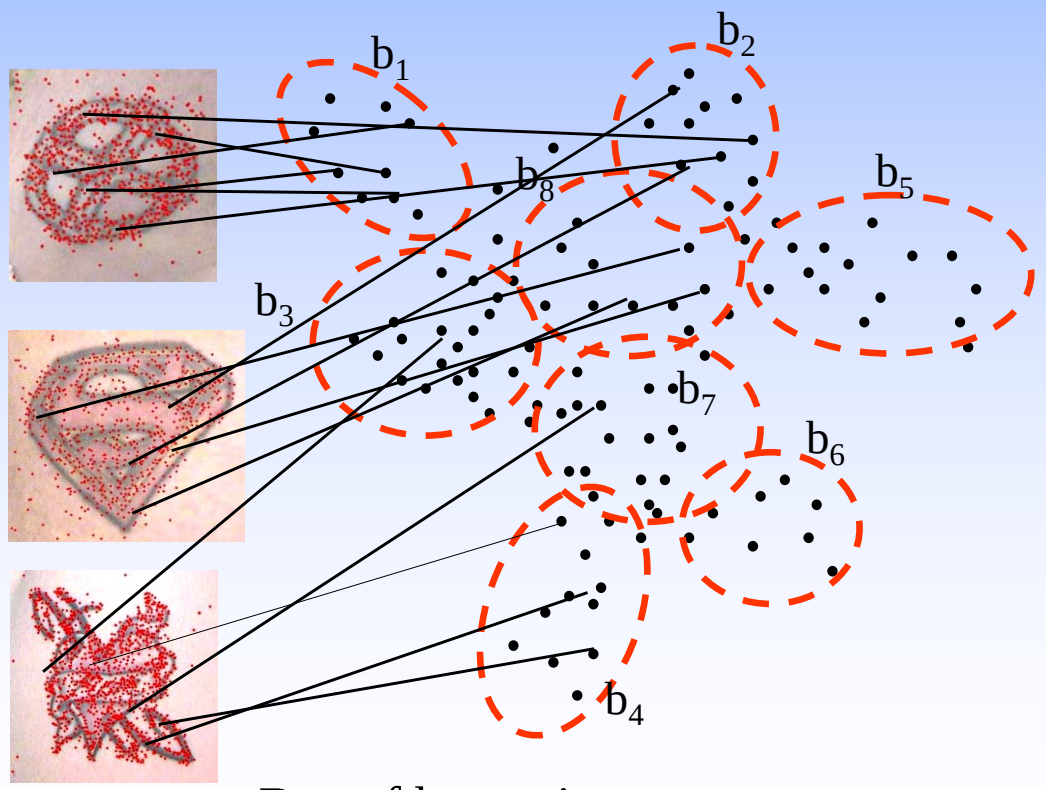
Given an image query, find the top-N most visually similar images in the database

Query

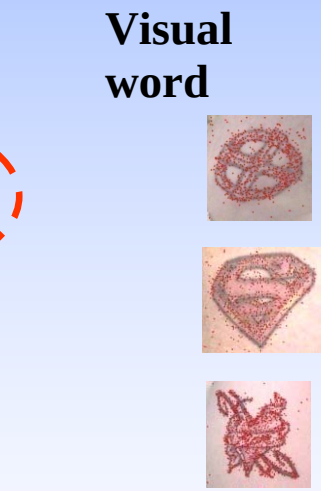

# Matching Near-Duplicate Tattoos

# Retrieval with Large Image Database

- Apply text-based search to image retrieval
  - Group key points from all the images into a number of clusters
  - Each cluster is a visual word
  - Bag-of-words representation for images
- Need to cluster billions of points!




Bag of key points




| $b_1$ | $b_2$ | $b_3$ | $b_4$ | $b_5$ | … |
|---|---|---|---|---|---|
| 5 | 2 | 0 | 0 | 0 | … |
| 0 | 1 | 3 | 0 | 0 | … |
| 0 | 0 | 1 | 4 | 0 | … |
| … | … | … | … | … | … |

Bag of words

# Retrieval Examples

Query

Top-5 Retrieved Images with match scores


Query 1


105


6

6


6

6

Query 2

79

73


24


22

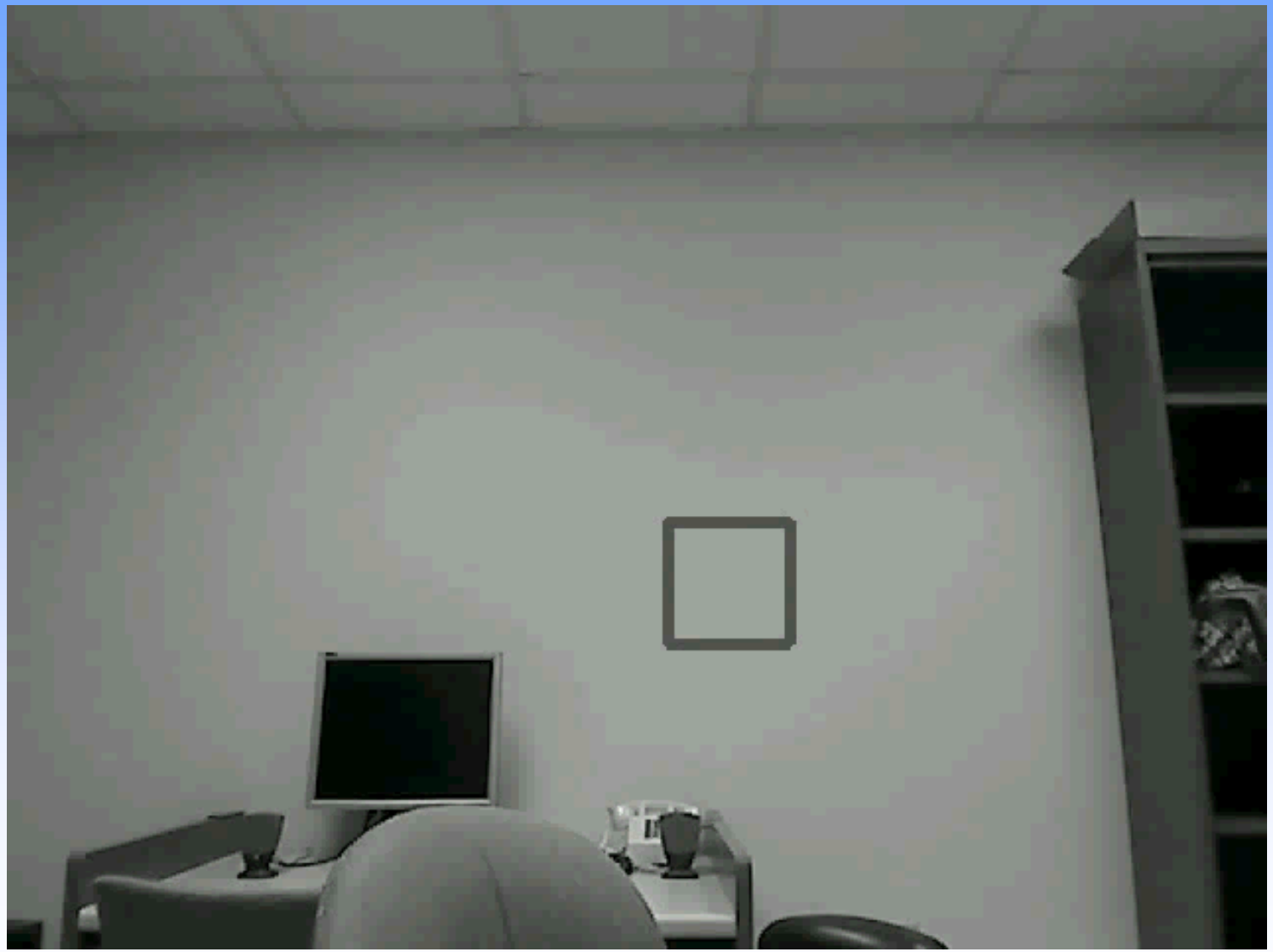
16

# Matching Performance

1,000 queries matched against 100K gallery images
(on Intel Core 2, 2.66 GHZ, 3 GB RAM)

| | Rank 1 (%) | Rank 20 (%) | Avg. Matching Time (sec) |
|---|---|---|---|
| Image information alone | 85.9 | 89.5 | 150.32 |
| With Tattoo Location | 89.1 | 92.7 | 6.26 |
| With Tattoo Location & Class | 90.6 | 94.2 | 2.9 |

# Continuous Authentication



# Challenges in Face Recognition

**Pose, lighting, expression**

**Occlusion**

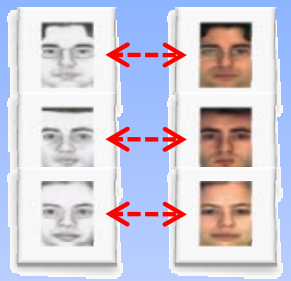
**Aging**


**Sketch vs. photo**

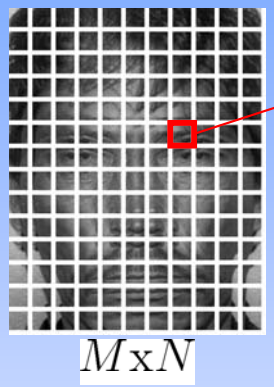
# Matching Sketches to Mugshots

## TRAINING

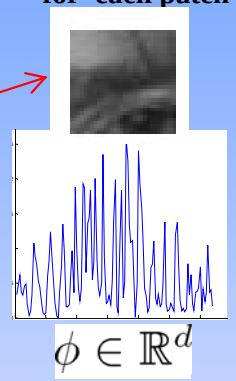
**Training set of sketch/photo correspondences**



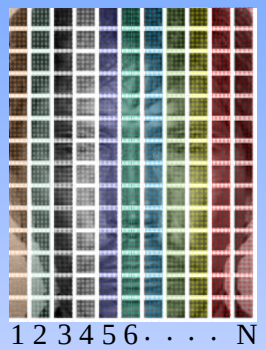
**Break each image into set of overlapping patches**




**GLOH or MLBP feature extraction for each patch**




**Group patch vectors into slices**




$$= \begin{bmatrix} \Phi(1) \\ \Phi(2) \\ \vdots \\ \Phi(N) \end{bmatrix}$$

**Learn discriminant projection for each slice**

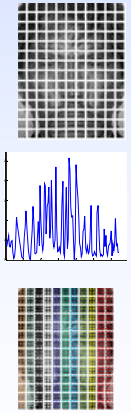
$$\begin{bmatrix} \Psi_1 \\ \Psi_2 \\ \vdots \\ \Psi_N \end{bmatrix}$$

## MATCHING

Probe Sketch

Gallery Photos

**Feature extraction and group into slices**



$$\begin{bmatrix} \Phi_s(1) \\ \Phi_s(2) \\ \vdots \\ \Phi_s(N) \end{bmatrix}$$

$$\begin{bmatrix} \Phi_p(1) \\ \Phi_p(2) \\ \vdots \\ \Phi_p(N) \end{bmatrix}$$

**Discriminant projection**

$$\begin{bmatrix} \Psi_1^{\mathrm{T}}\ \Phi_s(1) \\ \Psi_2^{\mathrm{T}}\ \Phi_s(2) \\ \vdots \\ \Psi_N^{\mathrm{T}}\ \Phi_s(N) \end{bmatrix} = \varphi_s$$

$$\begin{bmatrix} \Psi_1^{\mathrm{T}}\ \Phi_p(1) \\ \Psi_2^{\mathrm{T}}\ \Phi_p(2) \\ \vdots \\ \Psi_N^{\mathrm{T}}\ \Phi_p(N) \end{bmatrix} = \varphi_p^i \quad i = 1 \cdots n$$

**Matching**

**for** $i = 1 \cdots n$ **do**

$d(i) = ||\varphi_s - \varphi_p^i||_2$

**end for**

$\text{Identity} = \min(d)$

http://biometrics.cse.msu.edu/Publications/Face/KlareLiJain_forensicSketch_TechRp10.pdf

# Forensic Sketches

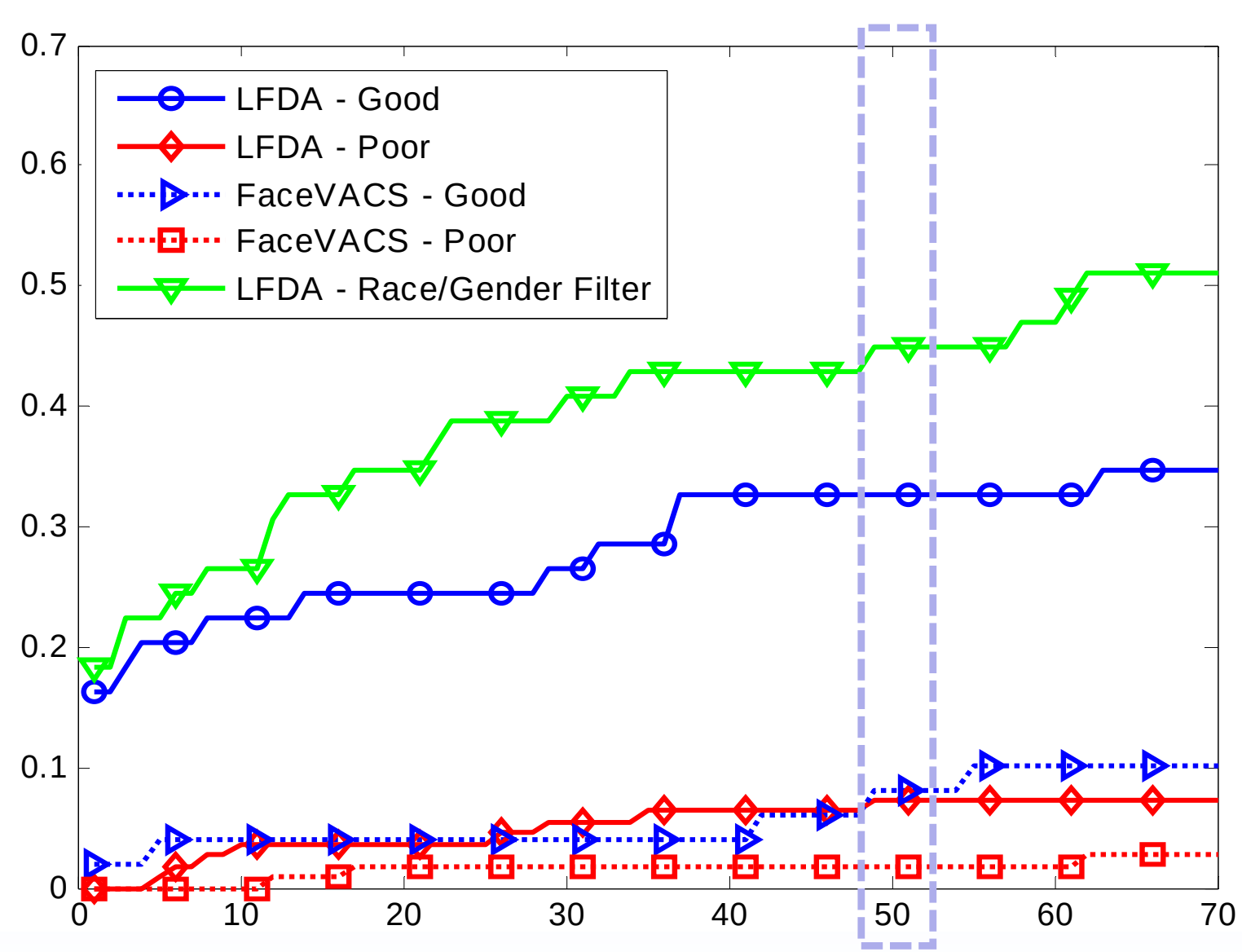
- Forensic sketch database
  - 159 total pairs of mated sketches and photos
  - *Good sketches*: look mostly similar to the subject
  - *Poor Sketches*: do not resemble the subject
- Demographic Information
  - Gender and race information
- Probe: 159 sketches; Gallery: 10,159 photos

Good Sketches

Poor Sketches

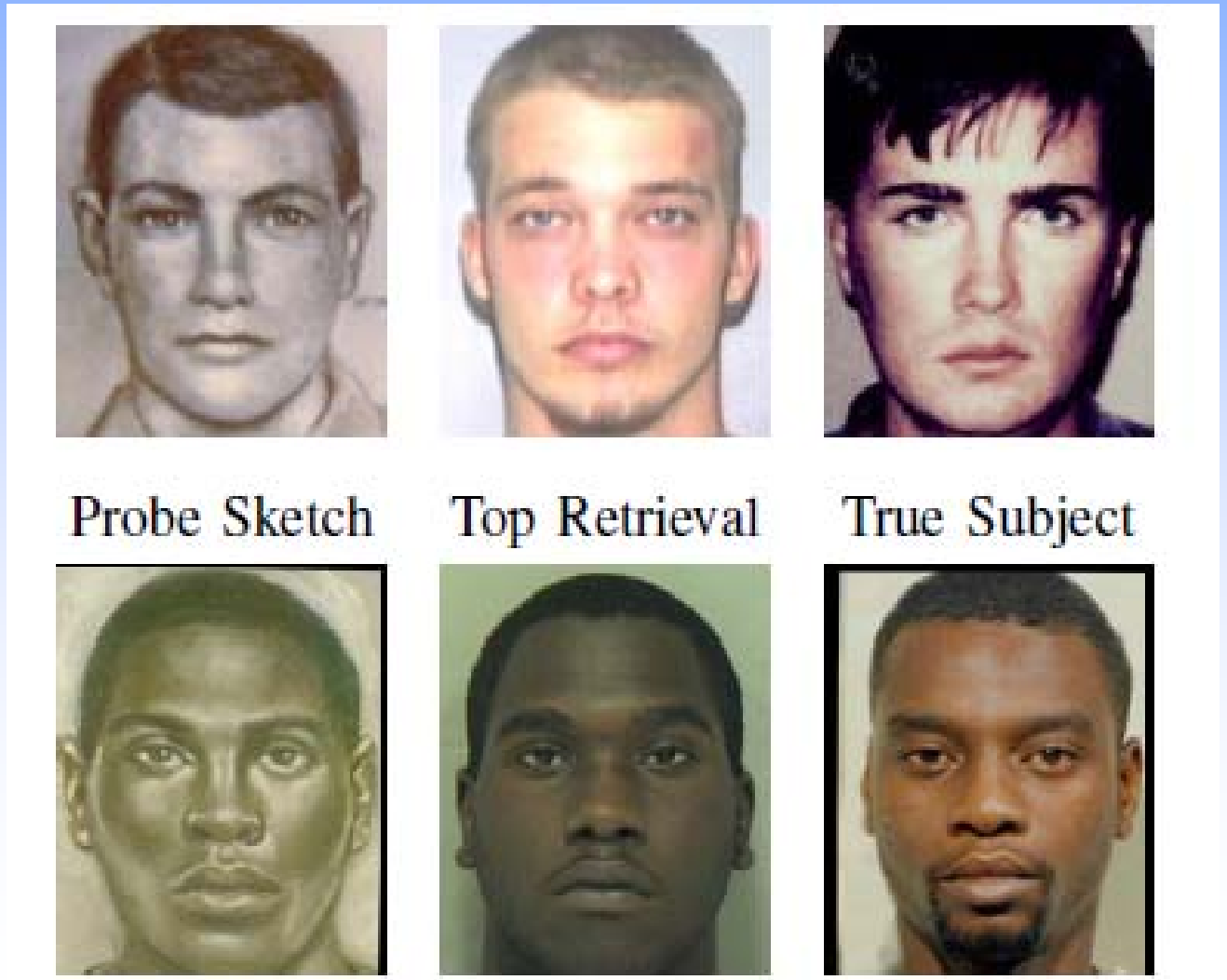
| | Forensic Sketches | Mugshot Gallery |
|---|---|---|
| Caucasian | 58.49% | 46.43% |
| African American | 31.45% | 46.93% |
| Other | 10.06% | 6.64 % |
| Male | 91.19% | 84.33% |
| Female | 8.81% | 15.52% |
| Unknown | 0.00% | 0.03% |

# Experimental Results



# Failed Examples

- Most failed matches were due to poorly drawn sketches with little resemblance to true photo



# Face Aging

- FR engines are not robust to aging
- Applications
  - Missing children, multiple enrollment
  - Age estimation (access control; vending machine)
- Goal: Age-invariant face recognition

**Age 3** **12** **33** **52**

Pairs of age-separated images of two subjects; FaceVACS failed to match them at rank-1

# Images

FG-NET

Age 2 5 10 16 19 29 40

MORPH

Age 25 36 40 43 48

BROWNS

Age 25 31 37 43 49 55

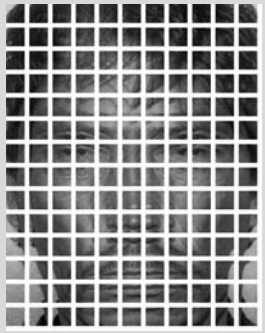
Northrop Grumman

Age 4 8 12 16 20

# Age Invariant Face Recognition

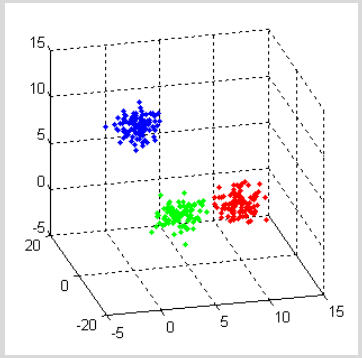
Training set
(age-separated images)

**Approach #1: aging invariant subspace learning**



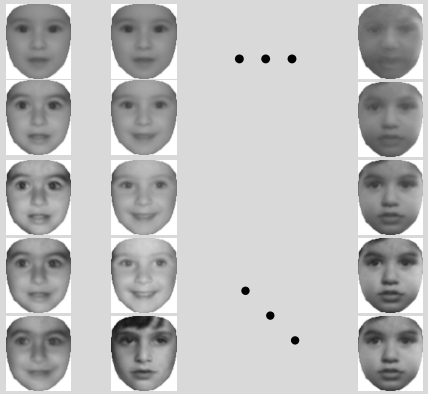
$$\begin{Bmatrix} \Phi_{SIFT}(1) \\ \vdots \\ \Phi_{SIFT}(M) \\ \Phi_{MLBP}(1) \\ \vdots \\ \Phi_{MLBP}(M) \end{Bmatrix}$$

Feature extraction & subspace learning




Build classifiers: Minimize within-subject variation & maximize between-subject variation

**Approach #2: appearance aging model**



Learn appearance aging pattern

$$\Phi' = \{\varphi_0, \varphi_1, \ldots, \varphi_N\}$$

3D aging model

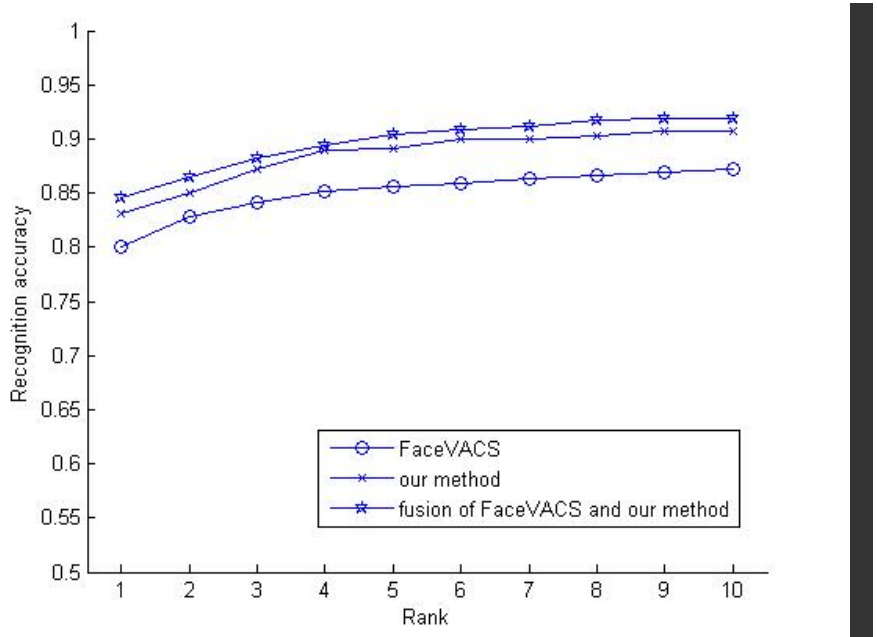
Input

Aging simulation

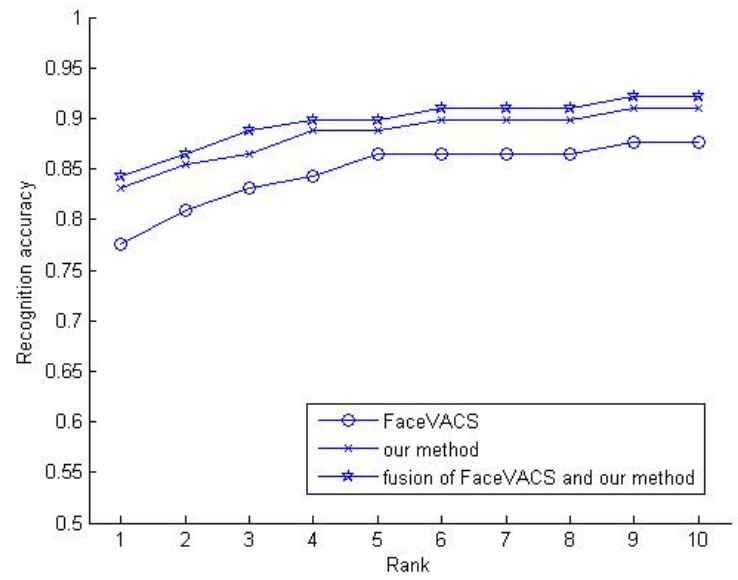
# Aging-Invariant Subspace Learning

- Training set: 1,679 images of 578 subjects from MORPH Album 1
- Testing set: MORPH Album 2
  - Probe: 10K probe images of 10K subjects
  - Gallery: 10K gallery images of 10K subjects
  - 2 age gaps between probe and gallery; probe age> gallery age

0-5 years gap




6+ years gap



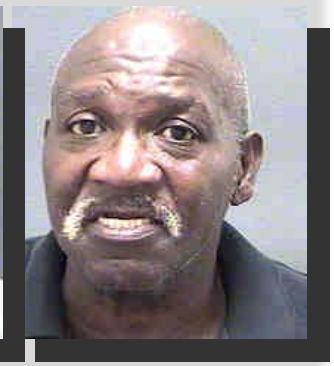
# Matching Results

Probe Images


Age 51


Age 40


Age 42


Age 62


Age 52


Age 29

Gallery Images


Age 41


Age 34


Age 41


Age 62


Age 42


Age 23

FaceVACS fails; proposed method succeeds

Proposed method fails
FaceVACS succeeds

Both methods fail
Fusion succeeds

# Summary

- Security will be more critical than ever in the ubiquitous networking era
- Use of biometric technology is inevitable to confirm user identity: travel documents, personal devices, government benefits, transactions,...
- Biometric recognition is not perfect; need to improve accuracy as well as system security
- Policy issues: risk of threat, risk of technology, cost, user convenience, user privacy, data ownership, recourse in case of misidentification