Biometric Recognition: Challenges in Forensics

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Identity Questions

- Does Charlie have a criminal record?
- Should John be granted a visa?
- Does Alice already have a driver license?
- Is Mary authorized to enter the facility?
- Can Steve access the website?
- Is Cathy the owner of the bank account?

We rely on credentials: documents & secrets

Al-Qaida Gets Fake Papers

James Sturcke & Agencies
Tuesday March 20, 2007
Guardian Unlimited

"An estimated 10,000 British passports were issued after fraudulent applications in the space of a year. Dhiren Barot, the most senior al-Qaida terrorist ever captured in Britain, had 7 passports in his true identity and 2 further passports in fraudulent identities."

290,000 passports issued by UK were lost/stolen in 2006

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

Passwords and PIN

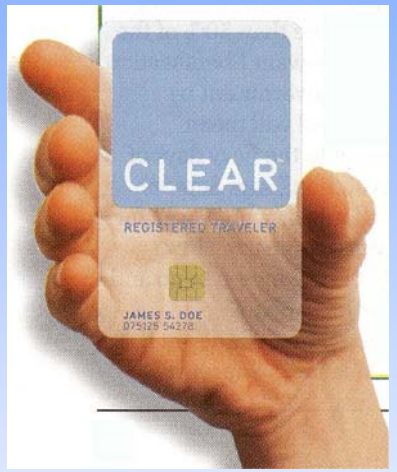
- Ten most common passwords: password, 123456, Qwerty, abc123, letmein, monkey, myspace1, password1, link182, (your first name)
  http://www.pcmag.com/article2/0,1895,2113976,00.asp
- ~40% of user-chosen passwords are readily guessable by programs
  http://portal.acm.org/citation.cfm?id=359168.359172
- Personal data is routinely lost & stolen
  http://www.privacyrights.org/ar/ChronDataBreaches.htm
- A complete identity (govt. issued ID, US bank account and new DOB) can be bought for $14
  The Straits Times, Singapore, March 20, 2007

Identity Theft

Identity thieves steal customer ID & pw to create financial nightmare for customers; 8.9 million ID thefts in U.S. in 2005 resulting in $56.6 billion losses

Biometric Recognition

Automatic recognition based on “who you are” as opposed to “what you know” (PIN) or “what you have” (ID card)



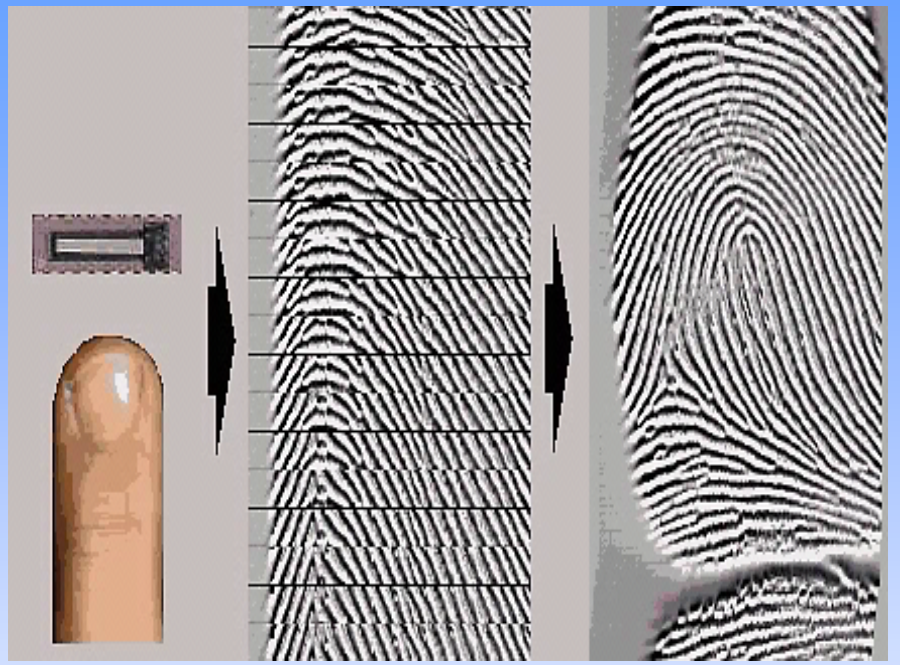
Recognition of a person by his body & then linking that body to an externally established identity, forms a very powerful tool for identity management

Biometrics is not New!

- Habitual Criminal Act, U.K. (1869)
- Bertillon system (1882) based on anthropometric measurements (height, length of foot, arm & index finger)
- Galton/Henry system of fingerprint matching adopted by Scotland Yard (1900)
- FBI set up a fingerprint identification division (1924)
- AFIS installed with a database of 800K fingerprints (1965)
- Goldstein (1971) published first face recognition paper
- Daugman (~1990) developed iris recognition technology
- FBI installed IAFIS in 2000 with a database of 80 million 10 prints; ~80,000 searches per day; ~20% of searches are in lights out mode; ~2 hour response time
- Next Generation Identification, NGI (2008); 1000 ppi, palmprints, extended feature definition, fusion

Biometric: New Era

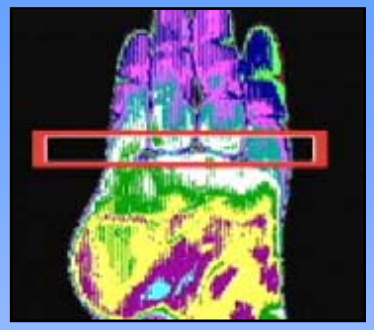
- Border security
- Multiple enrollments
- Financial fraud
- User convenience

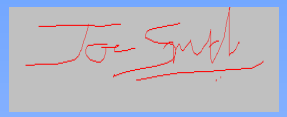


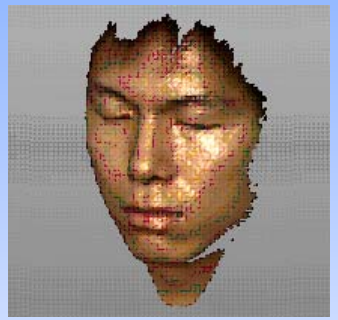
- Cheap & compact sensors
- Embedded systems
- Requirements: throughput, cost & HCI

Biometric Traits

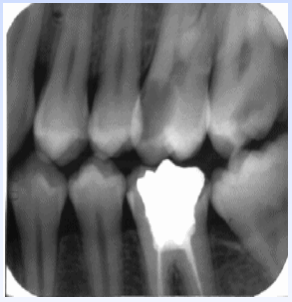


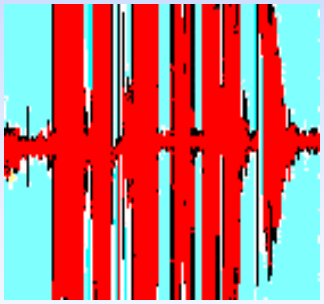
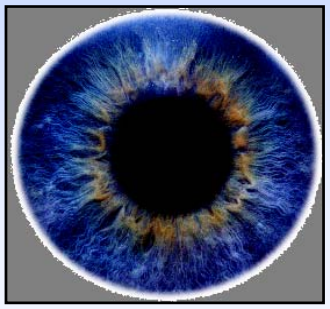
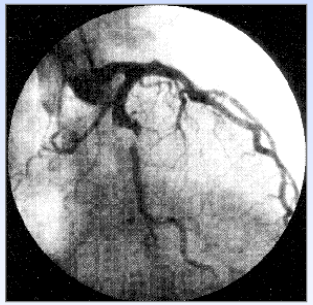




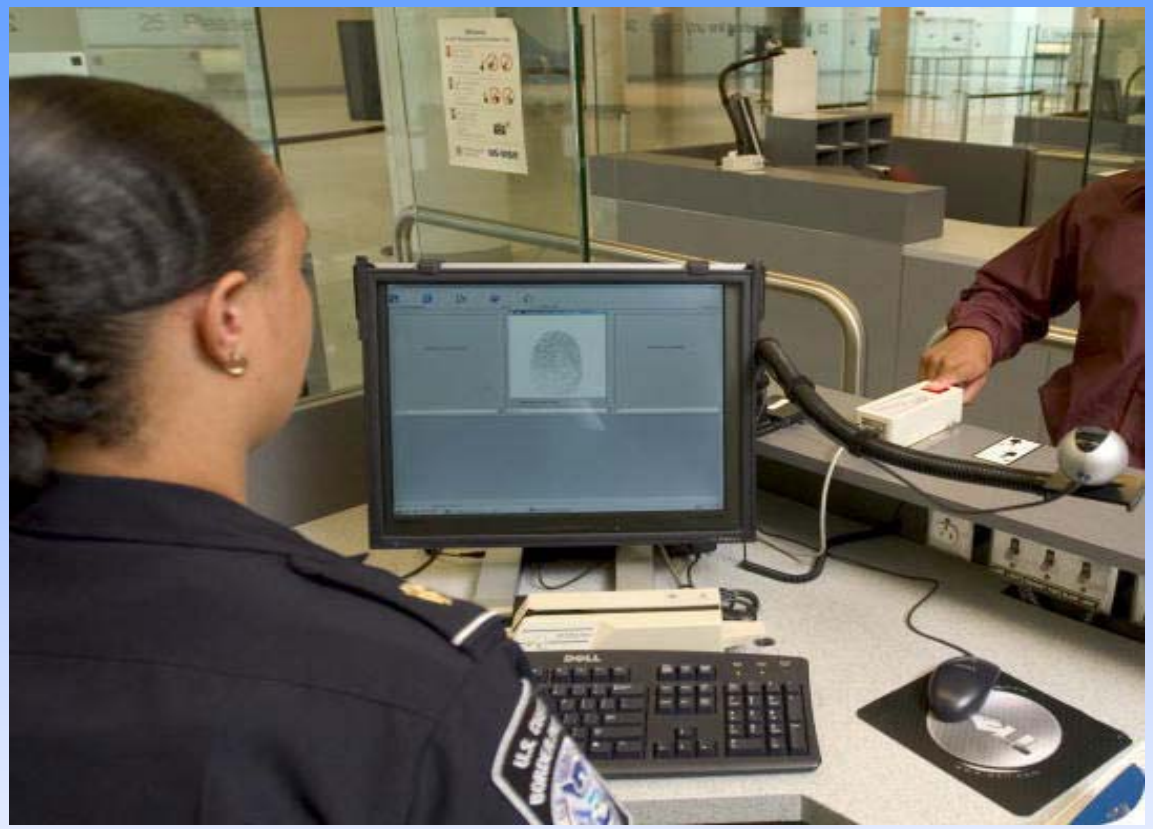




A biometric trait should satisfy: universality, distinctiveness, permanence and collectability

US-VISIT



~ 70M visitors have been processed by US-VISIT; 1,100 criminals denied entry; watch list size ~4M

Beginning Nov 27, 2007, Washington's Dulles Airport started to acquire ten fingerprints from each visitor to the US; system will be implemented at all land crossings by end of 2008

Singapore Biometric Passport

Fingerprint

Face

Started in August 2006

Border Crossing in UAE

Many people expelled from the UAE make repeated efforts to re-enter with new identities using forged travel documents

Disney World Orlando

Throughput: 100K/day, 365 days/ year; provides access to paying customers & denies access to non-paying customers

Commercial Applications

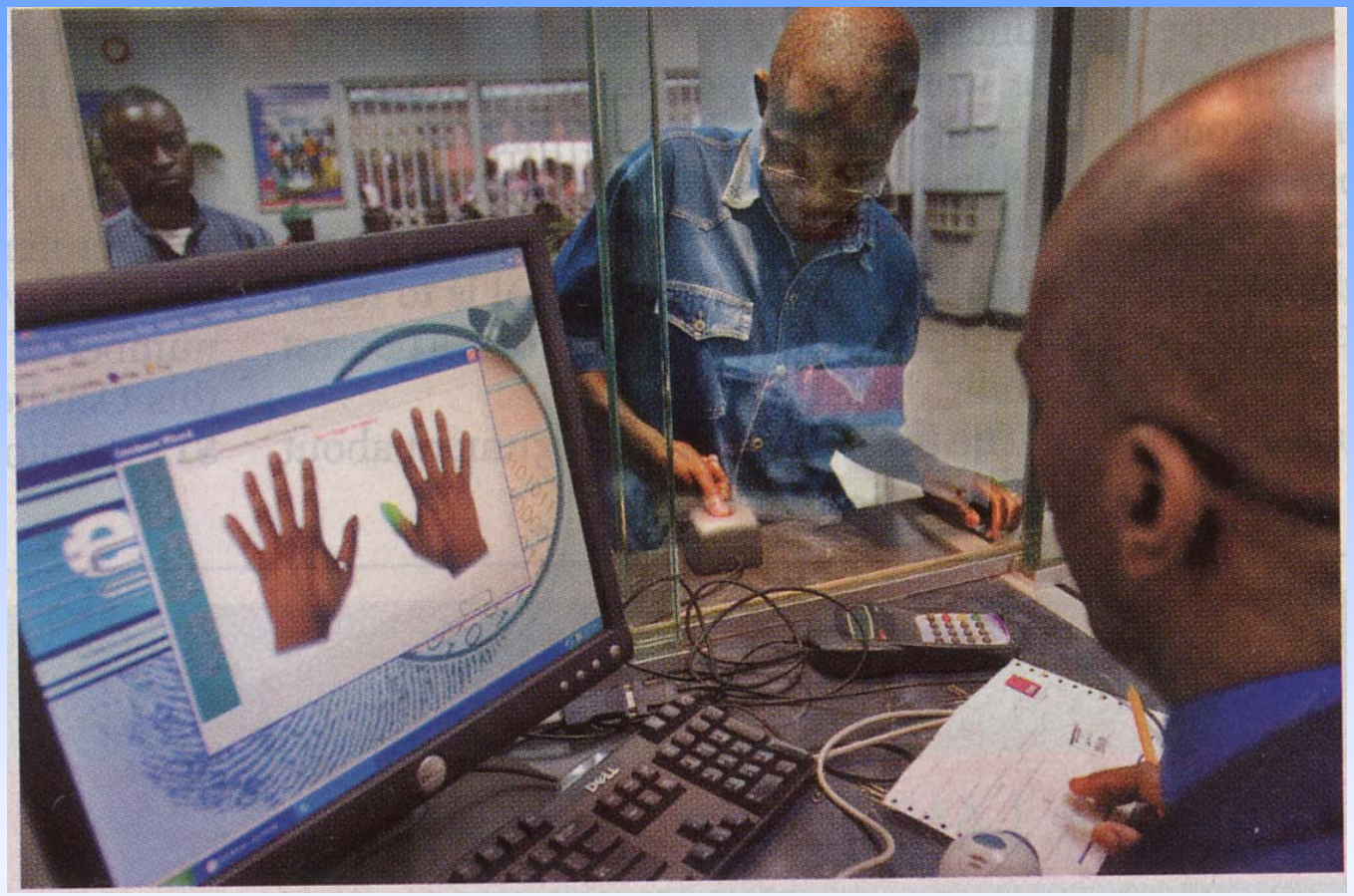
Meijer supermarket, Okemos

MSU Federal Credit Union, East Lansing

Citibank, Singapore: pay by fingerprints

Time & Attendance; Hilton Waterfront Beach Resort

Societal Benefits



Bank in Malawi uses fingerprint smart cards for micro-loans

Biometrics Research @ MSU

- Latent fingerprint matching
- Extended feature set
- Latent palmprint matching
- Scars, Marks and Tattoos (SMT)
- Facial aging
- Biometric fusion
- Template security
- Face recognition in video
- Whole hand sensing

Challenges in Forensic Science

- Tremendous increase in expectations from forensic science
  - "CSI effect"- Jurors are now more concerned about the physical evidences (fingerprints, DNA, etc.); suspects/convicts are being acquitted due to lack of physical evidence
  - Police detectives who used to gather 4-5 pieces of evidence from crime scenes now gather 50-400 sources
- Crime rate is falling but the backlog is still increasing; at the end of 2002 more than half a million cases were backlogged
- Throughput needs to be increased since samples can be stored only for a finite time period
- Need for better equipment, efficient techniques, and strong theoretical and empirical proofs of their effectiveness.

Max M. Houck, "CSI: The Reality", Scientific American, June 2006

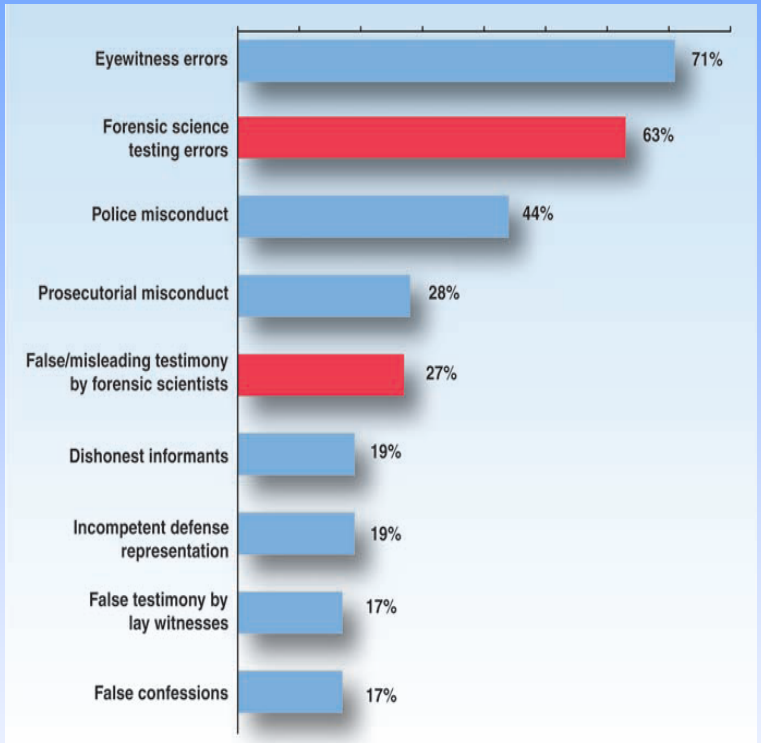
Paradigm Shift in Forensic Identification

- Old Paradigm: Assumption of discernible uniqueness
  - When pair of markings is not observably different, it is concluded that marks were made by the same person or object
  - No calculation or explanation of probabilities of random correspondence
- Emerging Paradigm: Rigorous proficiency testing
  - In Daubert v. Merrell Dow [509 U.S. 579 (1993)], the Supreme Court subjects the forensic sciences to a first-principles scientific scrutiny
    - Scientific plausibility of technique followed and proper error rate analysis of the forensic technique used is expected
  - Number of court challenges to forensic science is now increasing
    - In United States v. Starzecpyzel [880 F. Supp. 1027 (S.D.N.Y. 1995)], forensic document examination was not accepted
    - In a recent Baltimore court ruling, latent fingerprint evidence were excluded (http://www.clpex.com/Information/STATEOFMARYLAND-v-BryanRose.doc)

M. J. Saks and J. J. Koehler, "The Coming Paradigm Shift in Forensic Identification Science", Science, 309, pp. 892-895, 2005

Errors in Forensic Identification

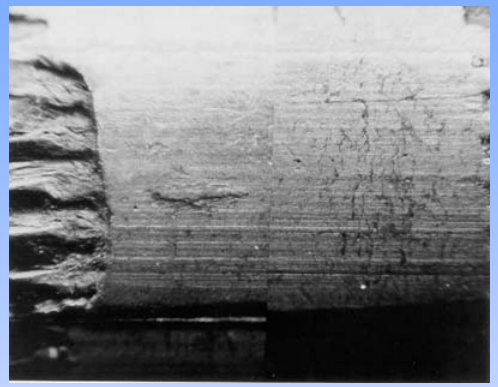
- Base error rates of forensic techniques
  - Spectrographic voice identification error rates are as high as 63%, Handwriting error rates-40%, Bite Marks-64%, Microscopic hair comparison-12%. In one test, 20% of latent examiners mistook one person's fingerprints for those of his twin
- Innocence Project
  - 14 people on death row were among the 87 exonerated by DNA analysis
    (http://www.innocenceproject.org/Content/73.php)



Factors associated with wrongful conviction in 86 DNA exoneration cases, based on case analysis data provided by the Innocence Project, Cardozo School of Law (New York, NY), and computed by us. Percentages exceed 100% because more than one factor was found in many cases. Red bars indicate factors related to forensic science.

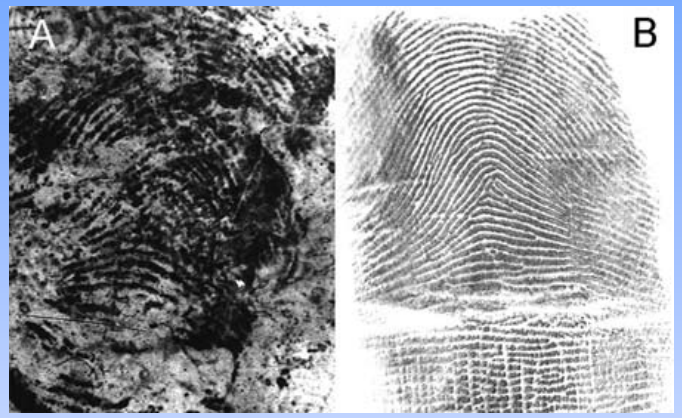
M. J. Saks and J. J. Koehler, "The Coming Paradigm Shift in Forensic Identification Science", Science, 309, pp. 892-895, 2005

Examples of Misidentifications



These illustrate subclass characteristics agreement which could be mistaken for individual characteristics

Bite mark misidentification which led to death sentence [State v. Krone, 182 Ariz. 319 (1995)]. Krone was exonerated a decade later by DNA analysis



FBI fingerprint examiners erroneously identified Brandon Mayfield as the Bomber in Madrid train bombing case

M. J. Saks and J. J. Koehler, "The Coming Paradigm Shift in Forensic Identification Science", Science, 309, 892-895, 2005

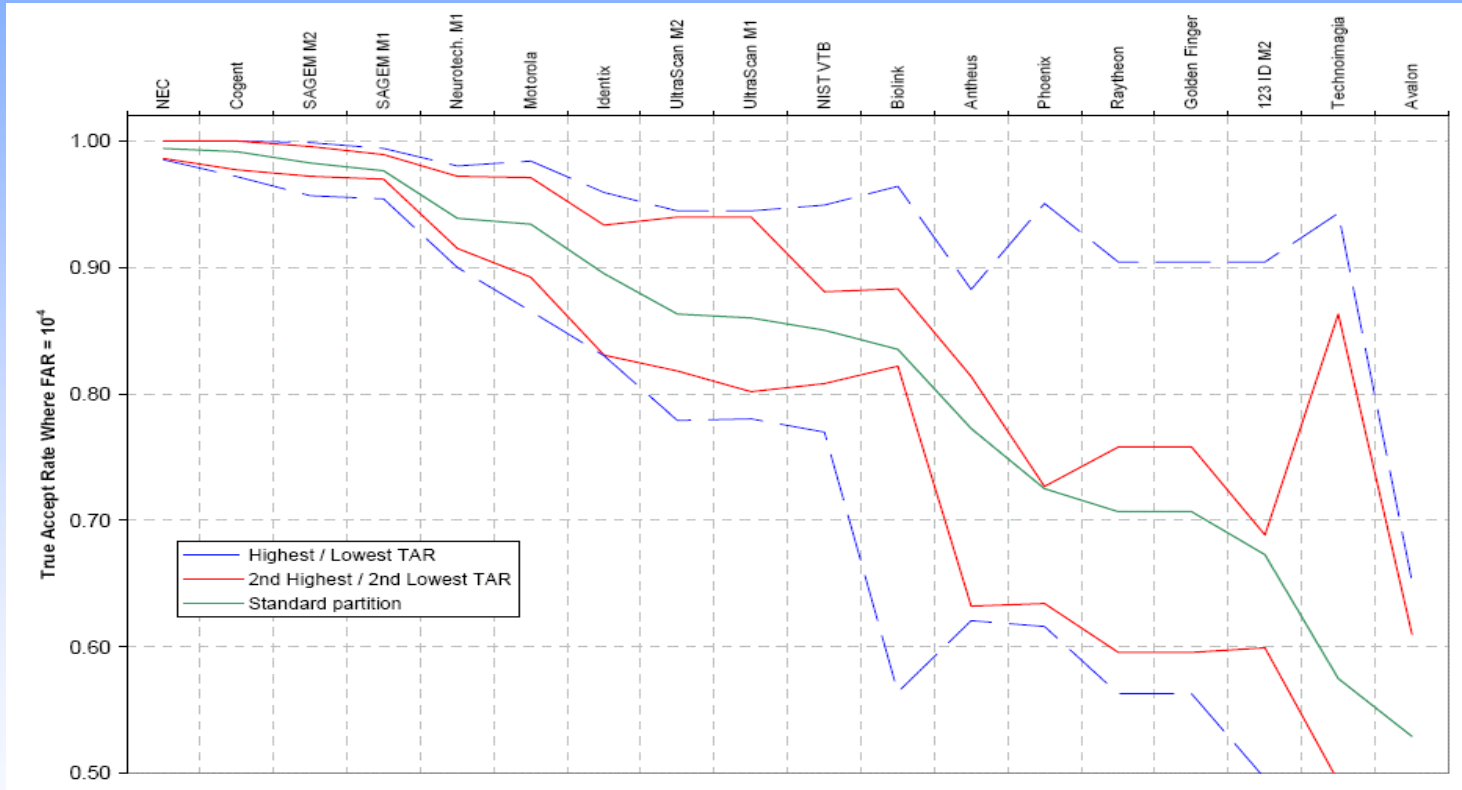
Fingerprints

"Perhaps the most beautiful and characteristic of all superficial marks (on human body) are the small furrows with the intervening ridges and their pores that are disposed in a singularly complex yet even order on the under surfaces of the hands and feet."

Francis Galton, Nature, June 28, 1888

Fingerprint Matching

NIST Fingerprint Vendor Technology Evaluation (FpVTE) 2003; the best matcher (NEC) achieved 99.4% TAR at 0.01% FAR.

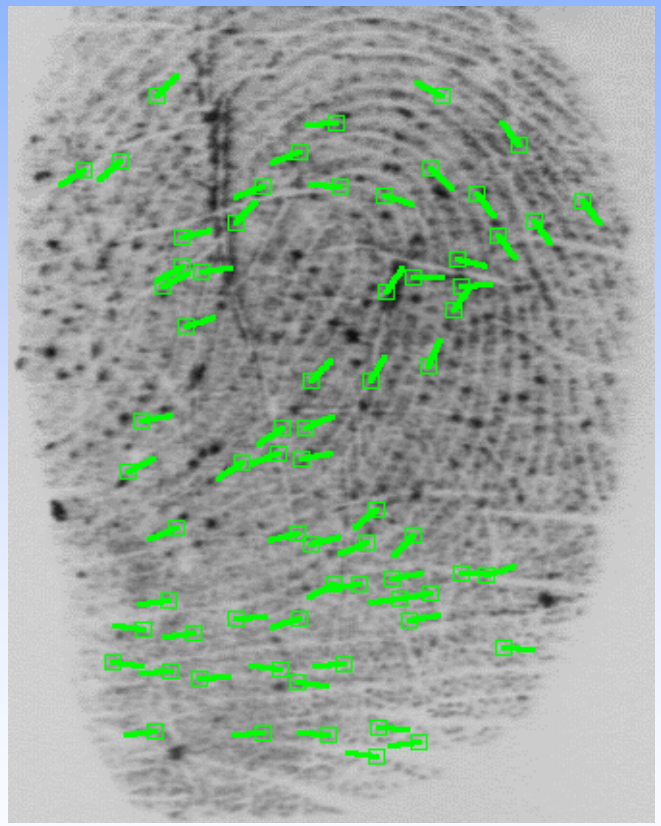


Results are based on 10,000 flat fingerprints

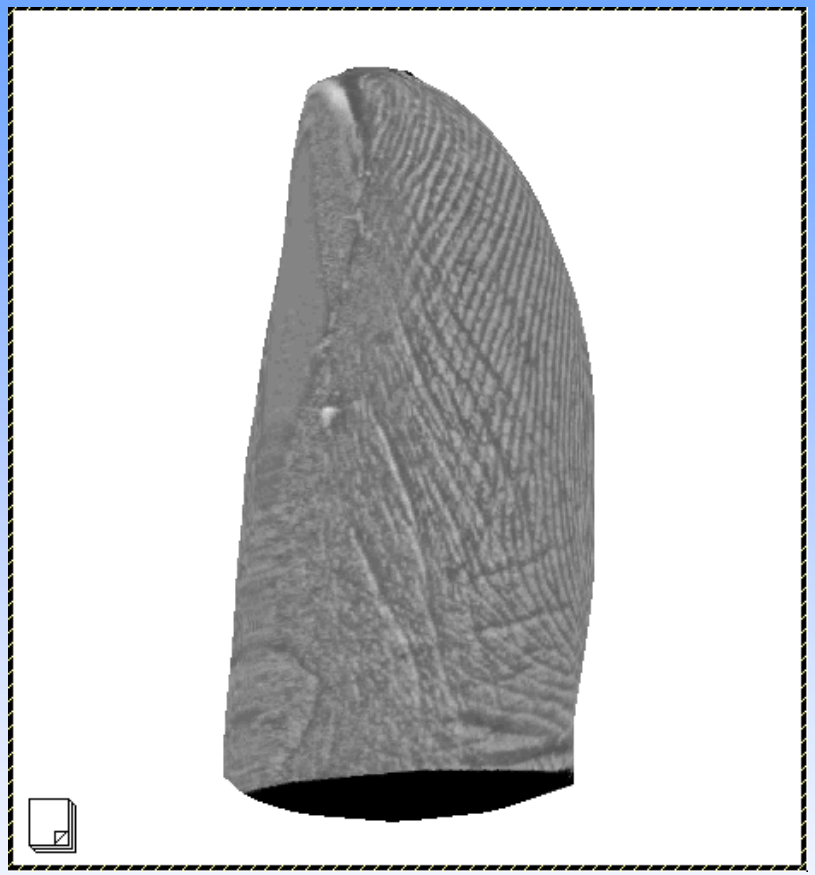
Challenges: low quality images, indexing, enhancing ”lights out” capability

Matching Errors

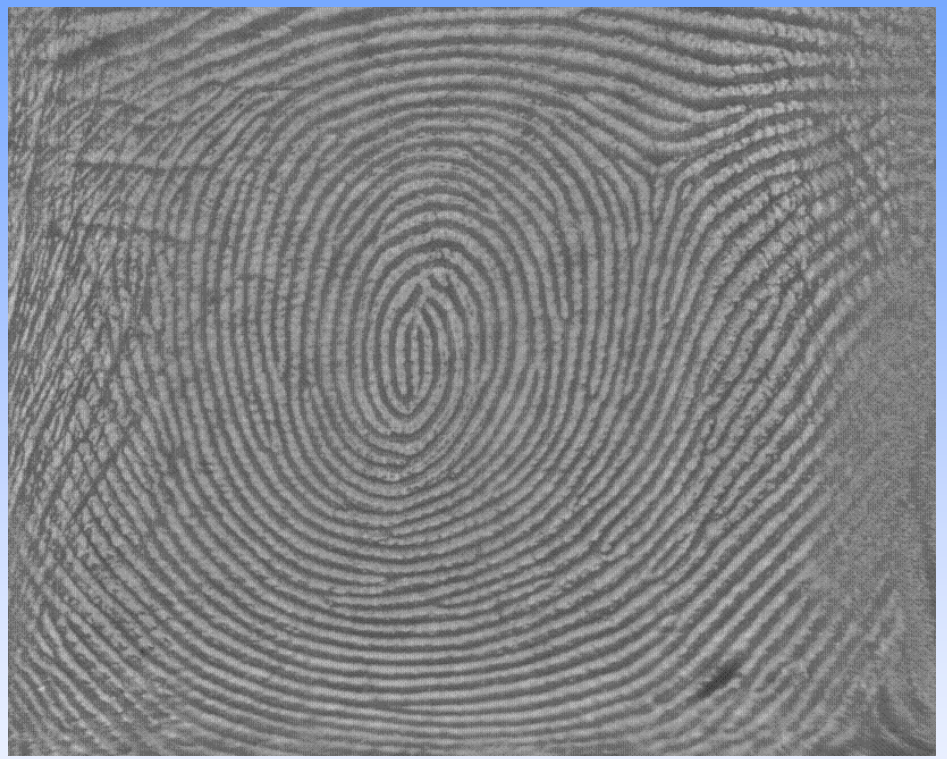
Large intra-class variation (distortion & noise)



Touchless Fingerprint Imaging



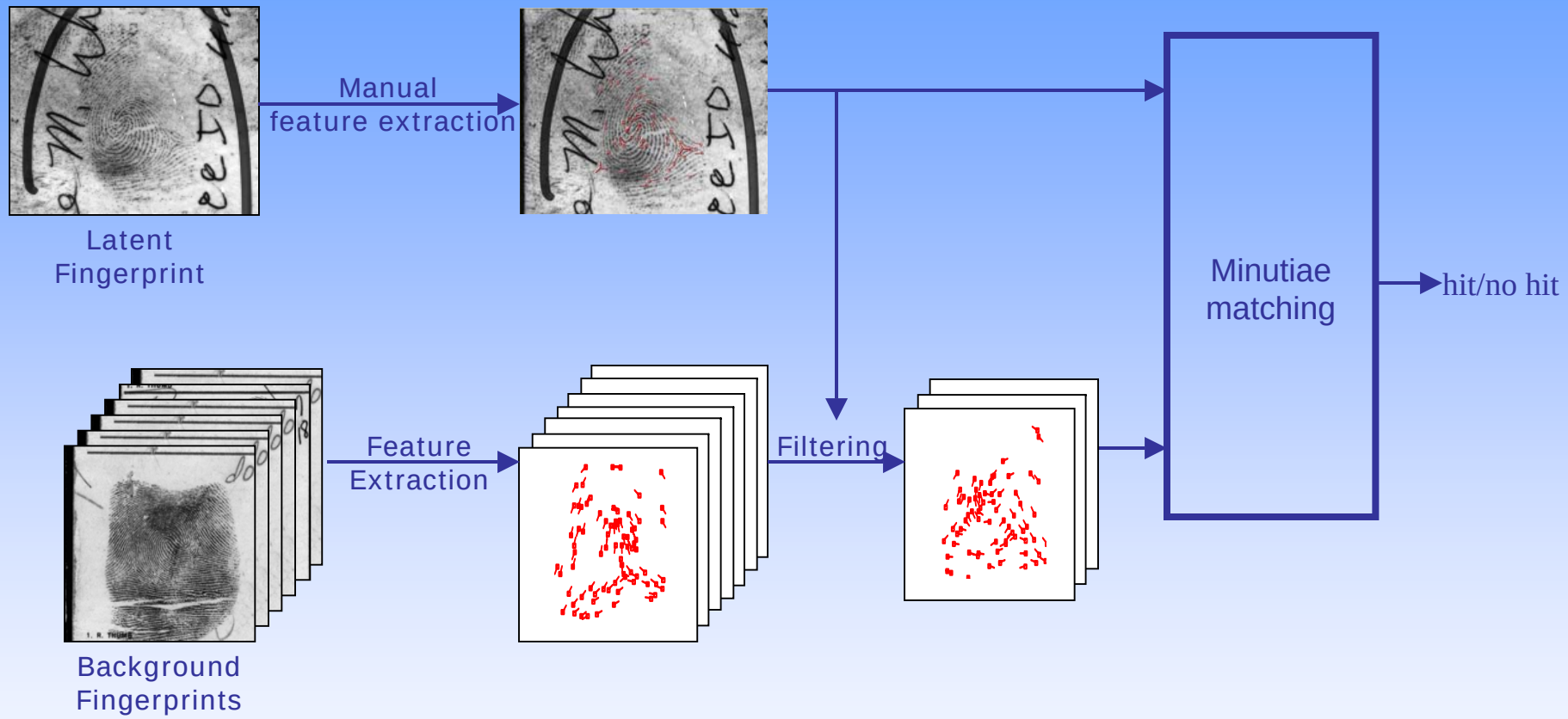
Touchless 3D image



Touchless “rolled” image

Courtesy: TBS North America (NIJ Fast Capture Program)

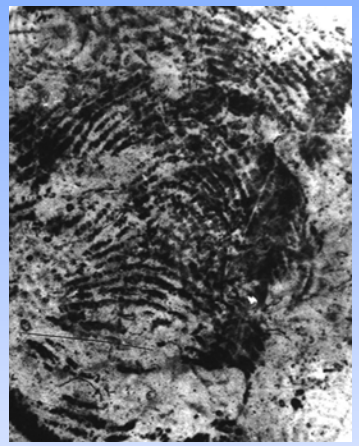
Latent Fingerprint Matching



Challenges: quality, distortion, limited information, automatic feature extraction, extended features, indexing

Reliability of Latent Identification

Latent fingerprint identification follows a strict protocol (ACE-V); errors inevitably occur due to "human factors"



Latent print
(Madrid bombing case)

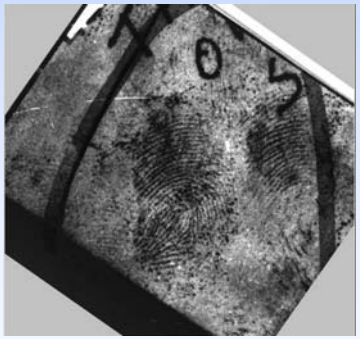
Actual matching rolled print
(Ouhnane Daoud)

Incorrectly matched rolled print
(Brandon Mayfield)

Would a better automatic matcher give a lower score for the above incorrect match, deterring an examiner to declare a "match"?

NIST Evaluation of Latent Fingerprint Technologies (ELFT) 2007

- ELFT is a multi-phase project aimed at testing state of the art latent fingerprint matching systems
- 15 SDK's were tested for matching performance
- Average rank-1 identification rate is ~**60%** (best ~**80%**) while searching 100 latents against a background database of 10,000 rolled prints
- Significantly lower accuracy than state of the art full print matching



Example of moderately difficult search successfully hit by most SDK's

Latent Fingerprint Research @ MSU

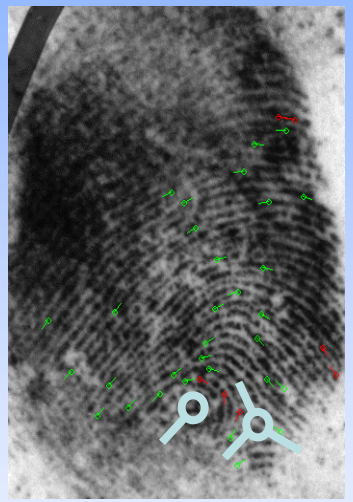
- Improved minutiae matching using orientation map, quality map, minutiae descriptor
- Multistage filtering
- Extended features
- Automatic feature extraction in latents

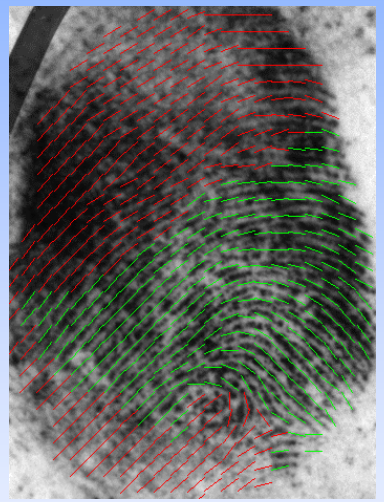
A.K. Jain, J. Feng, A. Nagar and K. Nandakumar, "On Matching Latent Fingerprints", IEEE Computer Society Workshop on Biometrics, CVPR, Alaska, 2008. (To Appear)

J. Feng and A.K. Jain, "Filtering Large Fingerprint Database for Latent Matching", Submitted to ICPR 2008

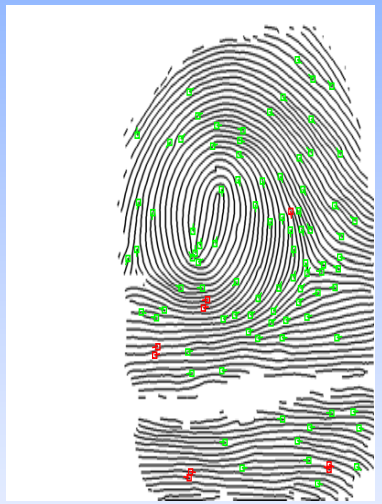
Feature Extraction

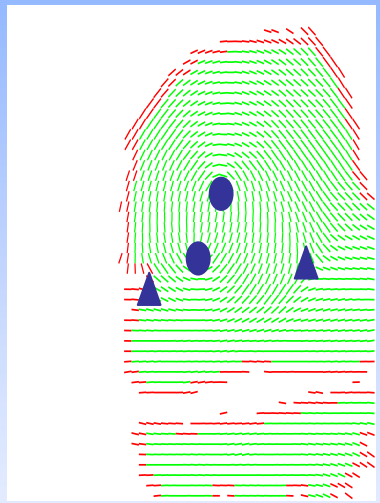
Latent Fingerprints
(Manual Extraction)





Rolled Fingerprints
(Automatic Extraction)



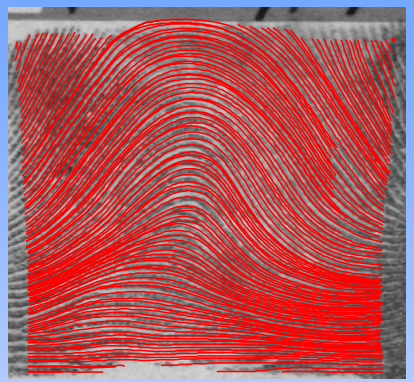


Minutiae, Core/Delta, Type, Orientation and Quality

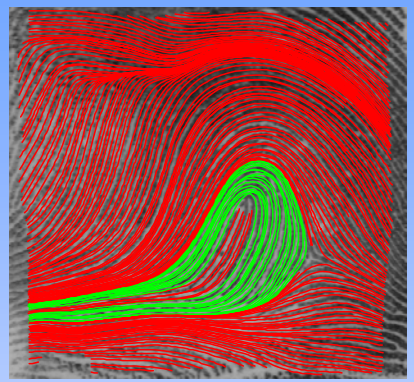
Red: unreliable
Green: reliable

Database Filtering

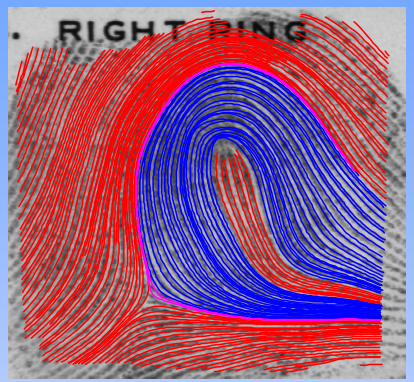
Fingerprint classification using pseudo ridges



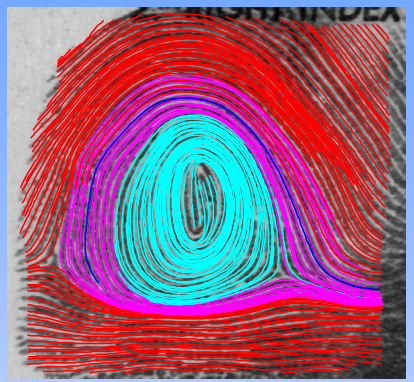
arch



left loop

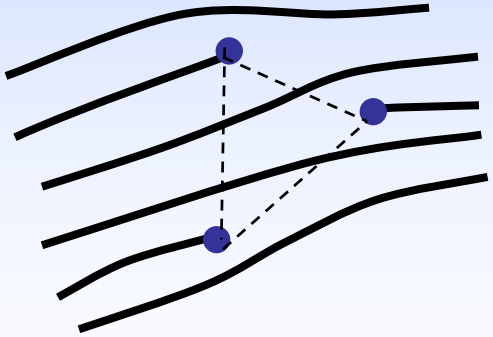


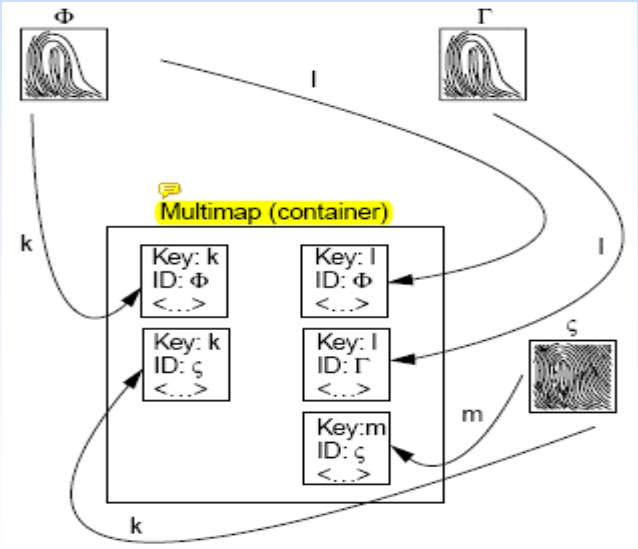
right loop



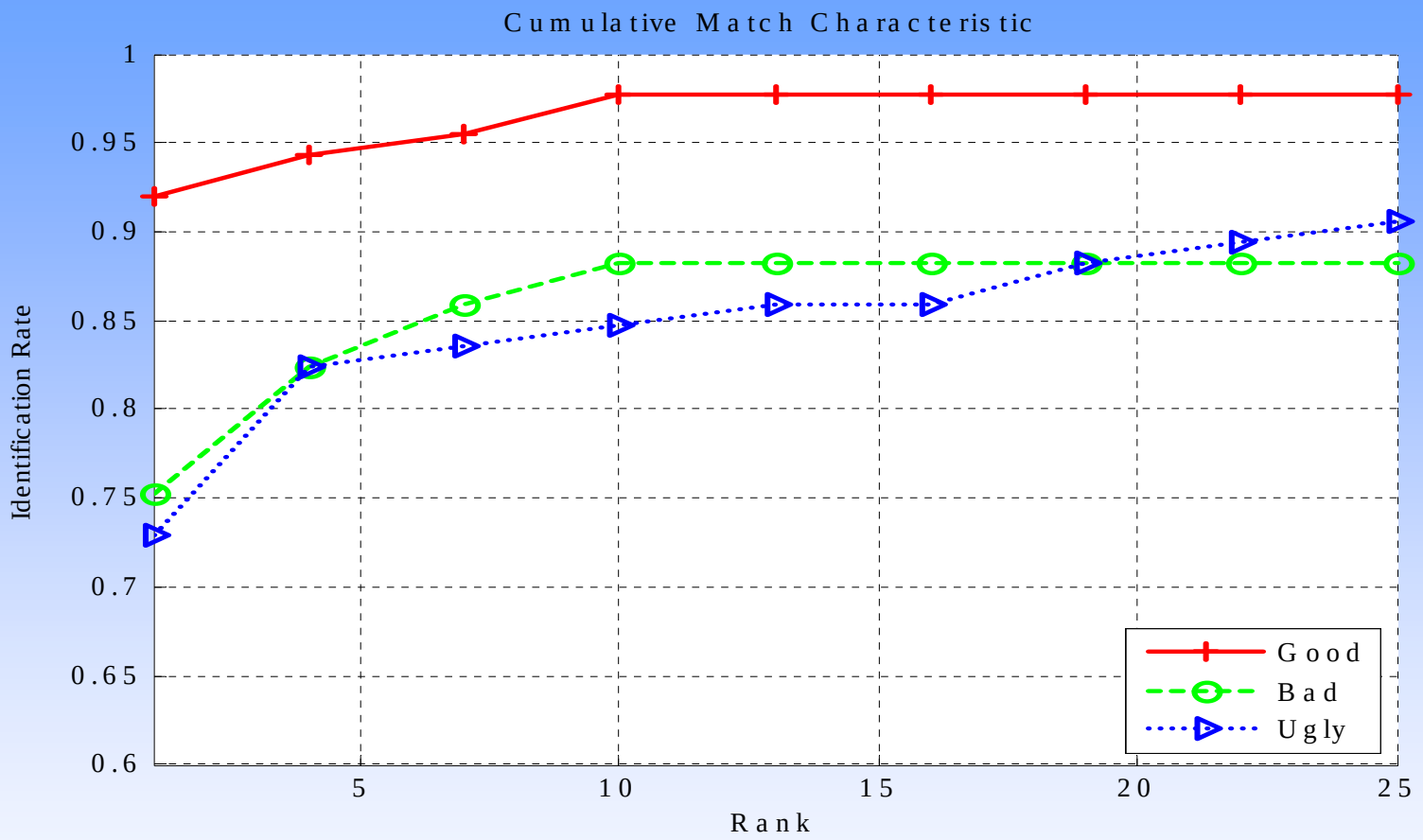
whorl

Minutiae triplet indexing



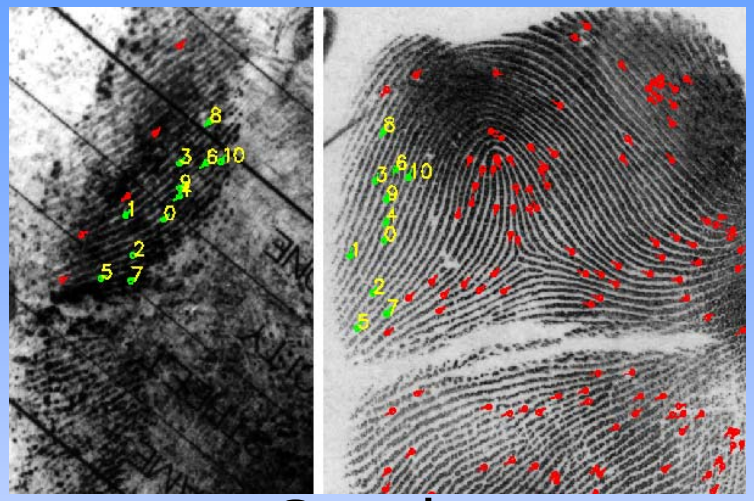


Matching Results

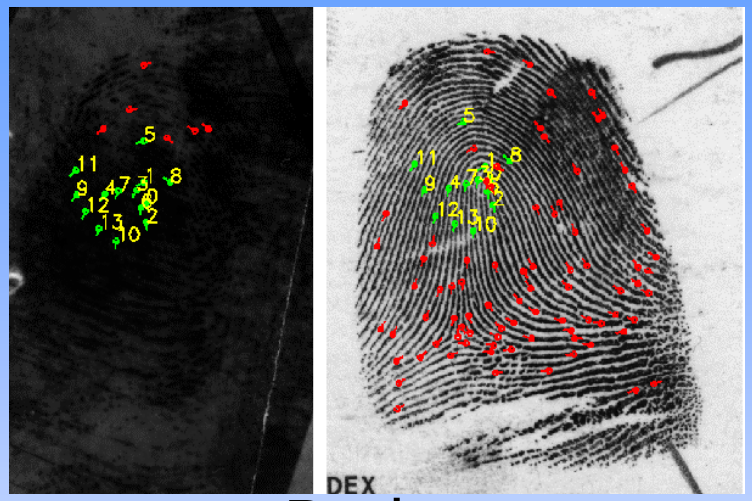


CMC curves corresponding to Good, Bad and Ugly quality latent images in the NIST SD-27 database. These three categories contain 88, 85 and 85 latent images, respectively. A background database of 2,258 rolled prints is used

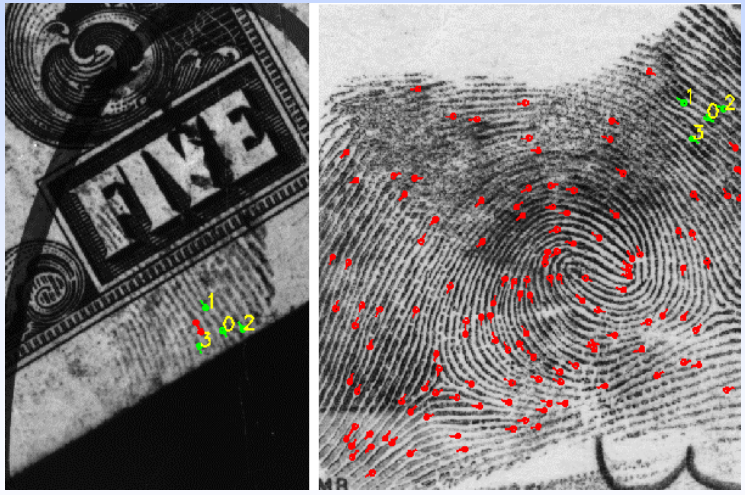
Correct Matches



Good



Bad

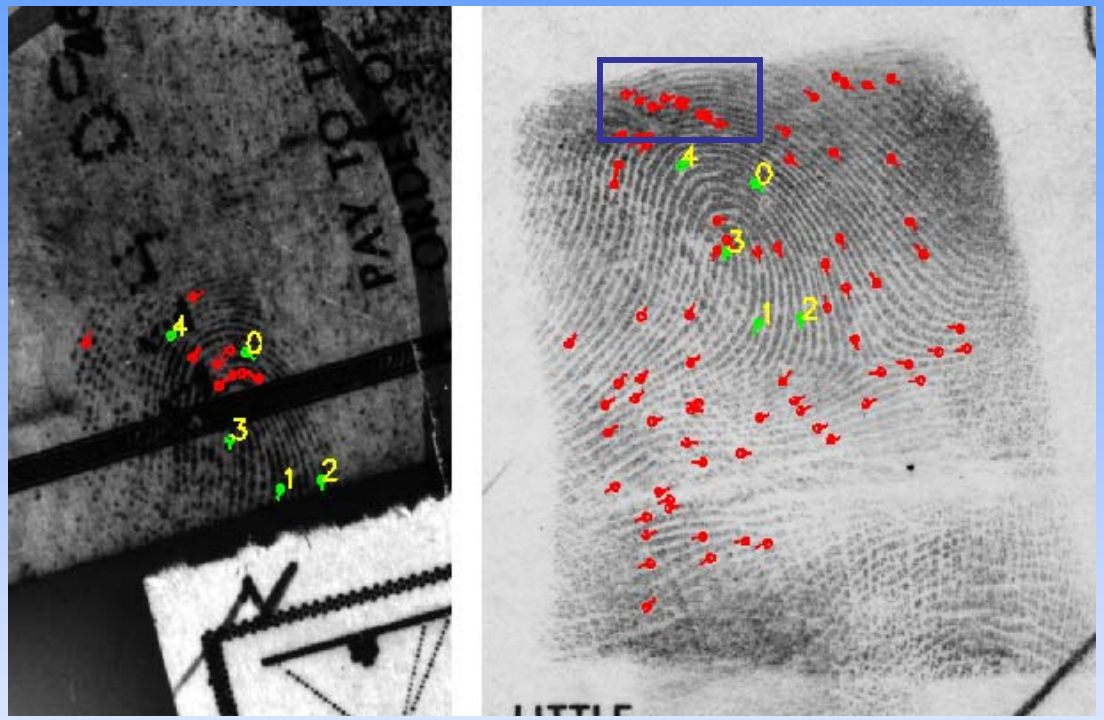


Ugly

Three latents (classified as good, bad and ugly by latent examiner) and the mated rolled prints. **In all these three cases, our algorithm found the true mates at rank one.**

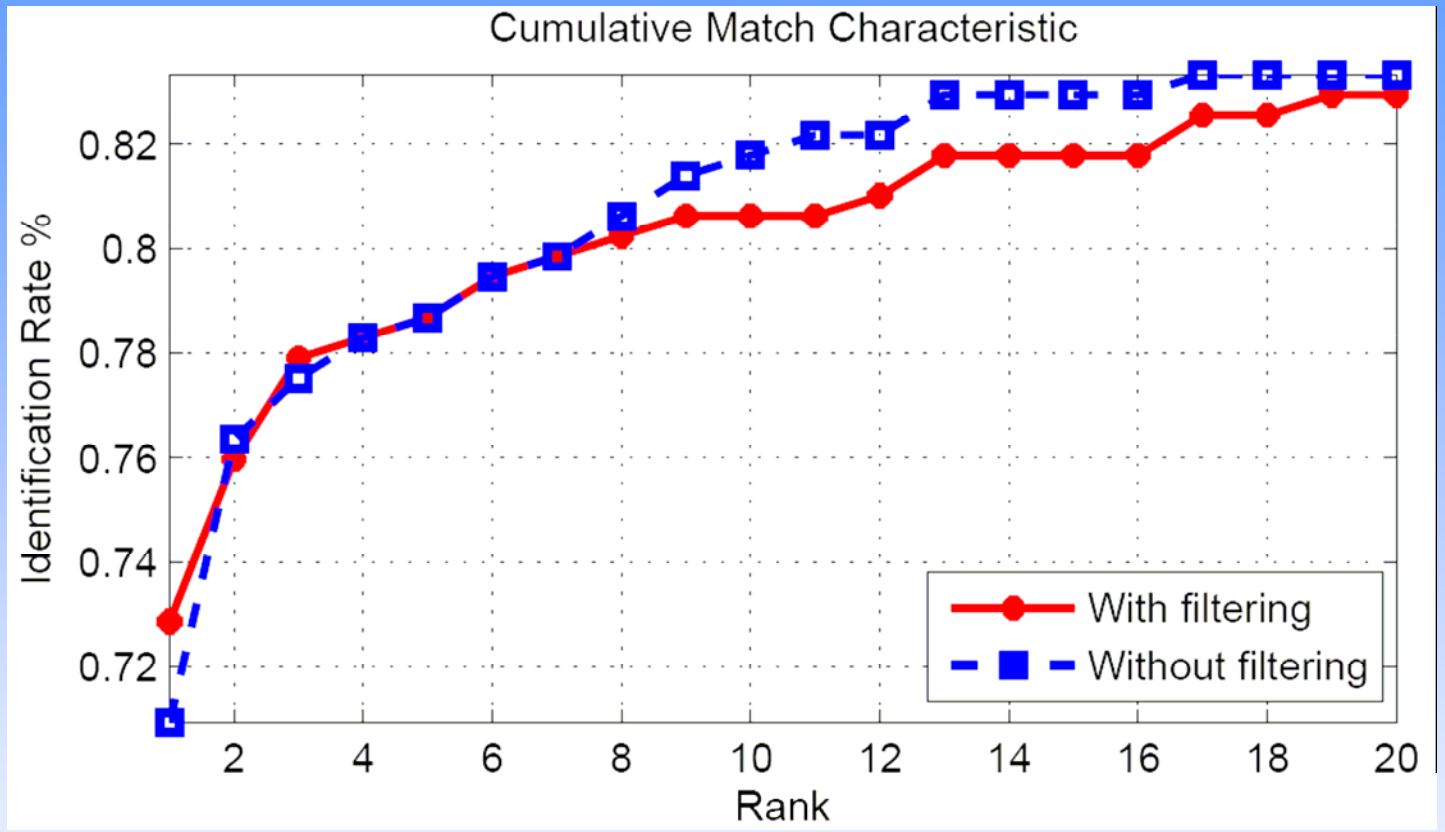
Matching minutiae are shown in green; index of matching minutiae are shown in **yellow**; unmatched minutiae are shown in red

Incorrect Match



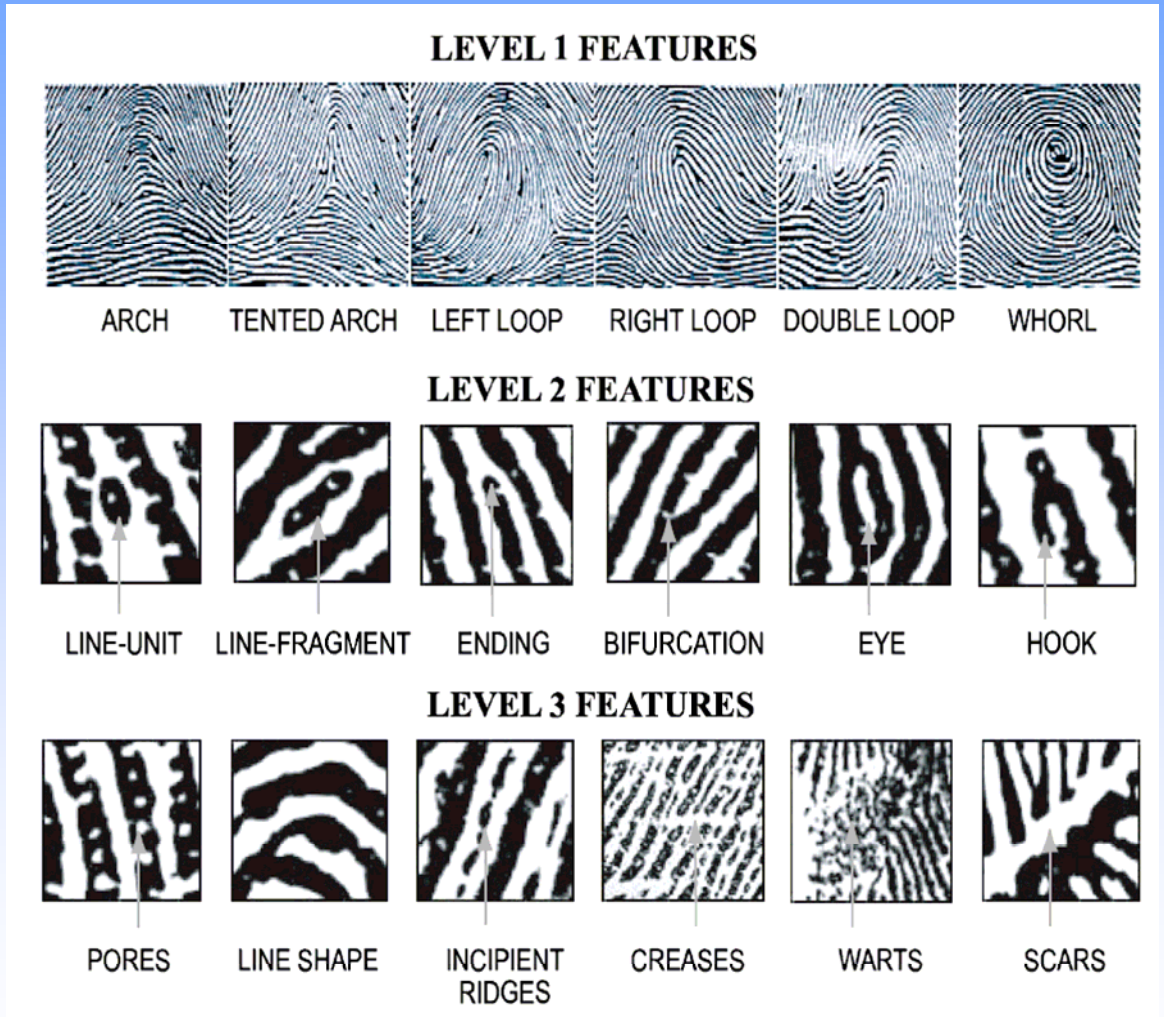
The mated rolled print (right) of the latent (left) was ranked 245 by our algorithm. Many spurious minutiae are detected in the rolled print; matching minutiae are shown in **green**; index of matching minutiae are shown in **yellow**; unmatched minutiae are shown in **red**

Filtering Performance



CMC curves of with and without filtering on a background database of 10,258 full prints (258 from NIST27, 2,000 from NIST4, and 8,000 from NIST14); searching a latent with filtering takes 62 seconds, 3 times faster than without filtering

Extended Fingerprint Features



- Level 1 (Patterns)
- Level 2 (Points)
- Level 3 (Shape)

Extend Features

- Current AFIS systems do not utilize extended features while 52% of practitioners affirm to always use them when present on a mark
- A new ANSI/NIST standard on extended feature set is being drafted by CDEFFS, which includes standard definitions and representations of pores, dots and incipient ridges
- An online survey (2006) regarding Level 3 features among 70 practitioners found out that dots are the most reproducible and valuable Level 3 features

"What are level 3 characteristics and their role in fingerprint identification? A survey among practitioners", A. Anthoniioz et al., 2006

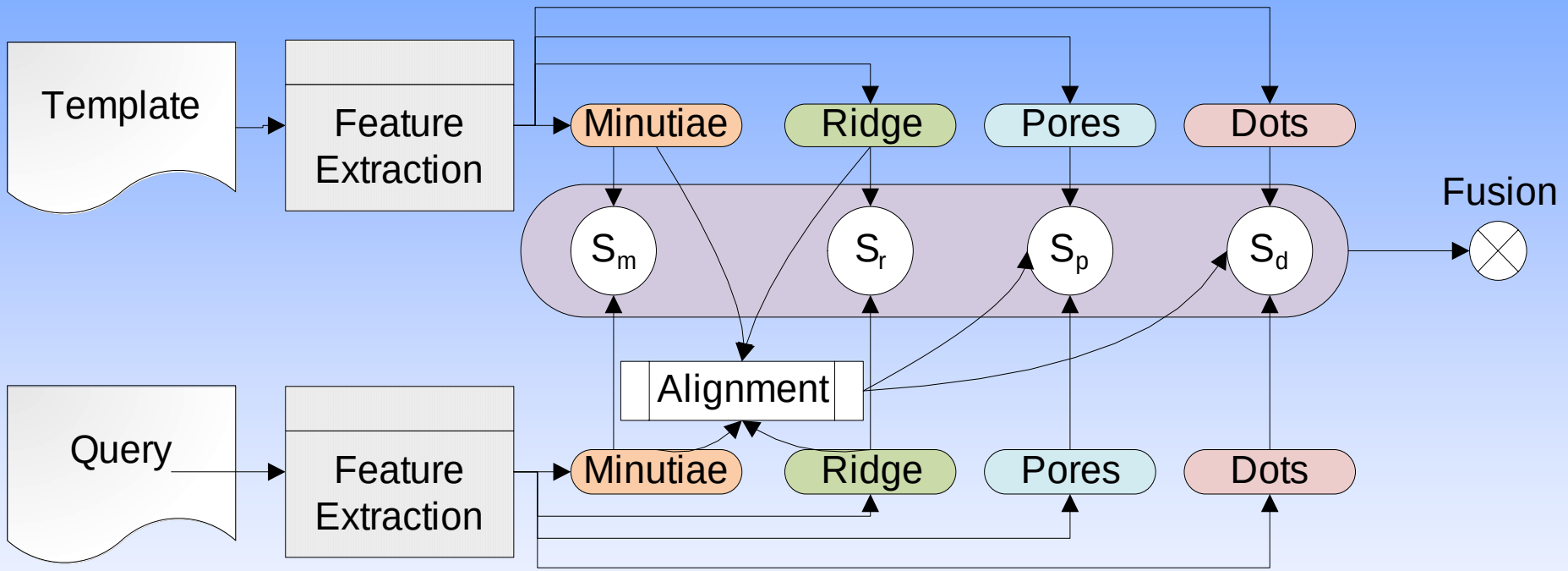
Extend Features Research @ MSU

- Extraction and utilization of pores, ridge contours, dots, incipient ridges
- Fusion of extended features in minutiae matcher

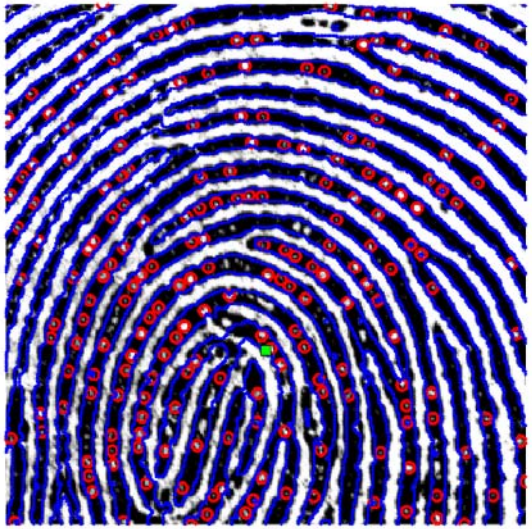
A.K. Jain, Y. Chen and M. Demirkus, "Pores and Ridges: High Resolution Fingerprint Matching Using Level 3 Features", *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 29, No. 1, pp. 15-27, January 2007

Y. Chen and A. K. Jain, "Dots And Incipients: Extended Features for Partial Fingerprint Matching", *Proceedings of Biometric Symposium, Biometric Consortium Conference*, Baltimore, September, 2007

Our Approach



Pores and Ridge Contours



Pores

- Equally spaced along ridges; avg. no. is 9 to 18/cm of a ridge
- Of varying size (88-220 micra in diameter), shape (round, elliptical, oval, square, rhomboid) and status (open, close)

Ridge Contours

- Shape of the ridge edge
- Created by (i) differential growth of the ridge units, and (ii) pores near the edge of the ridge

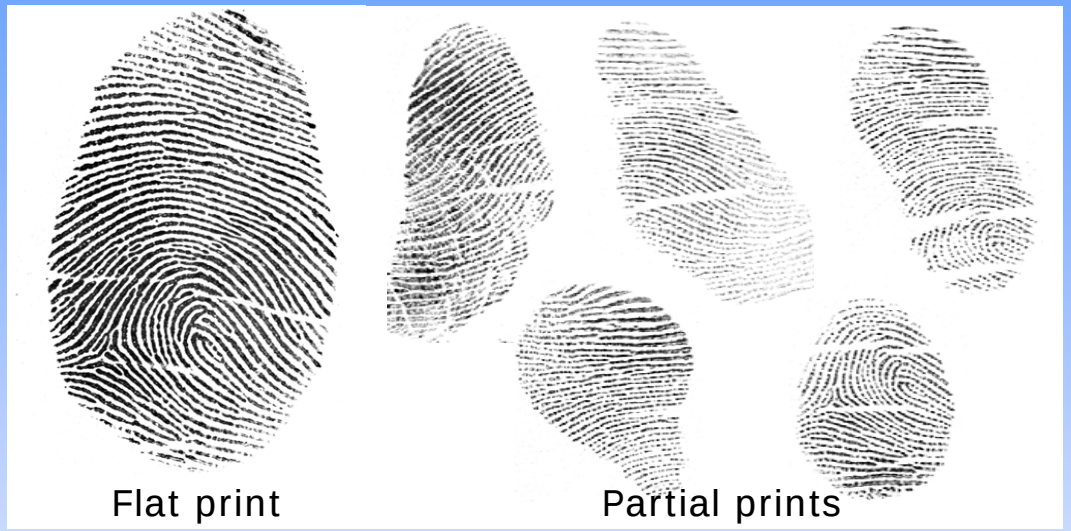
Locard, *Les pores et l'identification des criminals,* Biologica, vol.2, pp. 357-365, 1912

Ashbaugh, D., *Quantitative-Qualitative Friction Ridge Analysis*, 1999, CRC Press

Database

In-house flat database

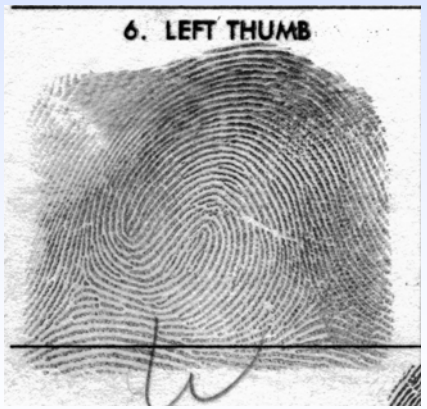
In-house partial database



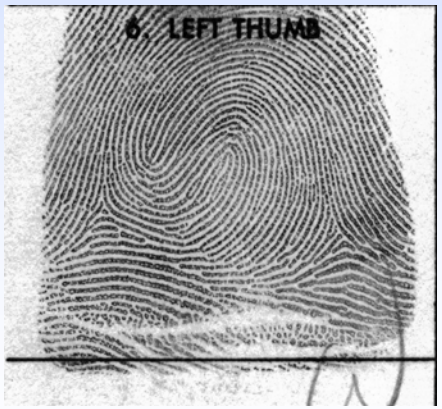
Flat print

Partial prints

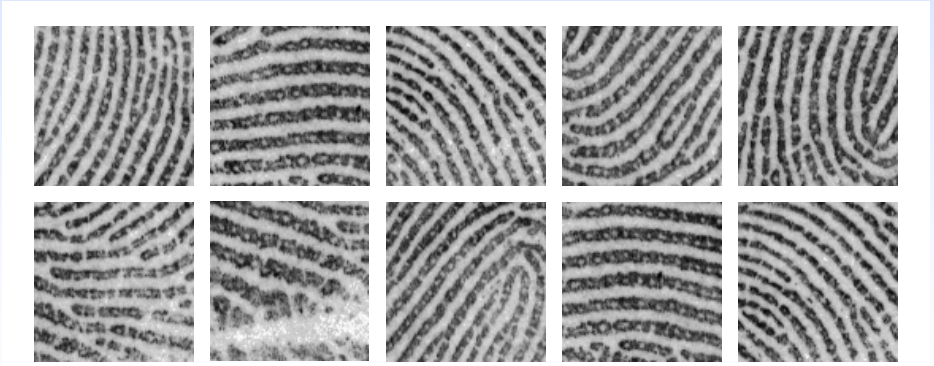
NIST Tenprint database (SD 30)



Roll 1



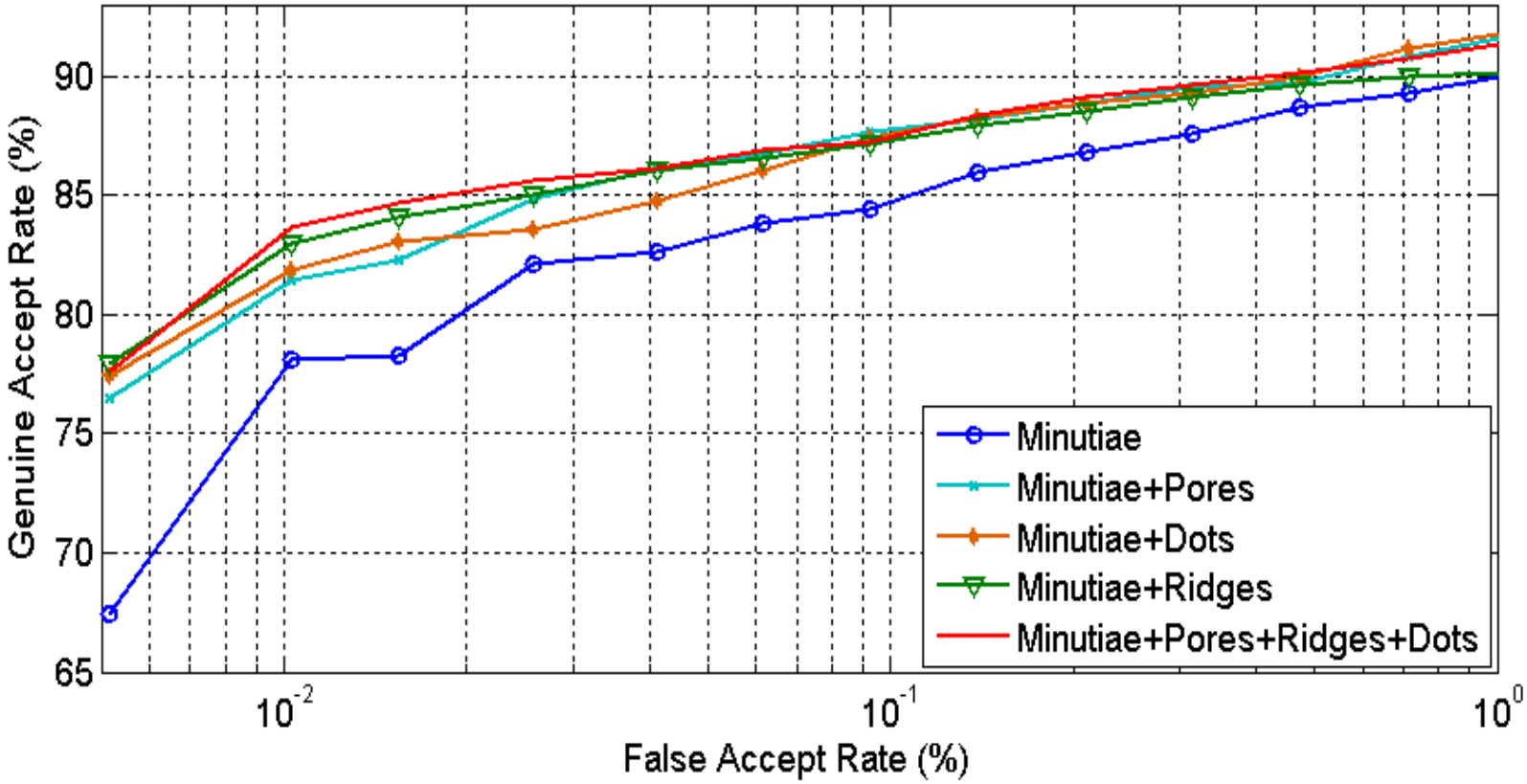
Roll 2



Cropped Partials from Roll 2

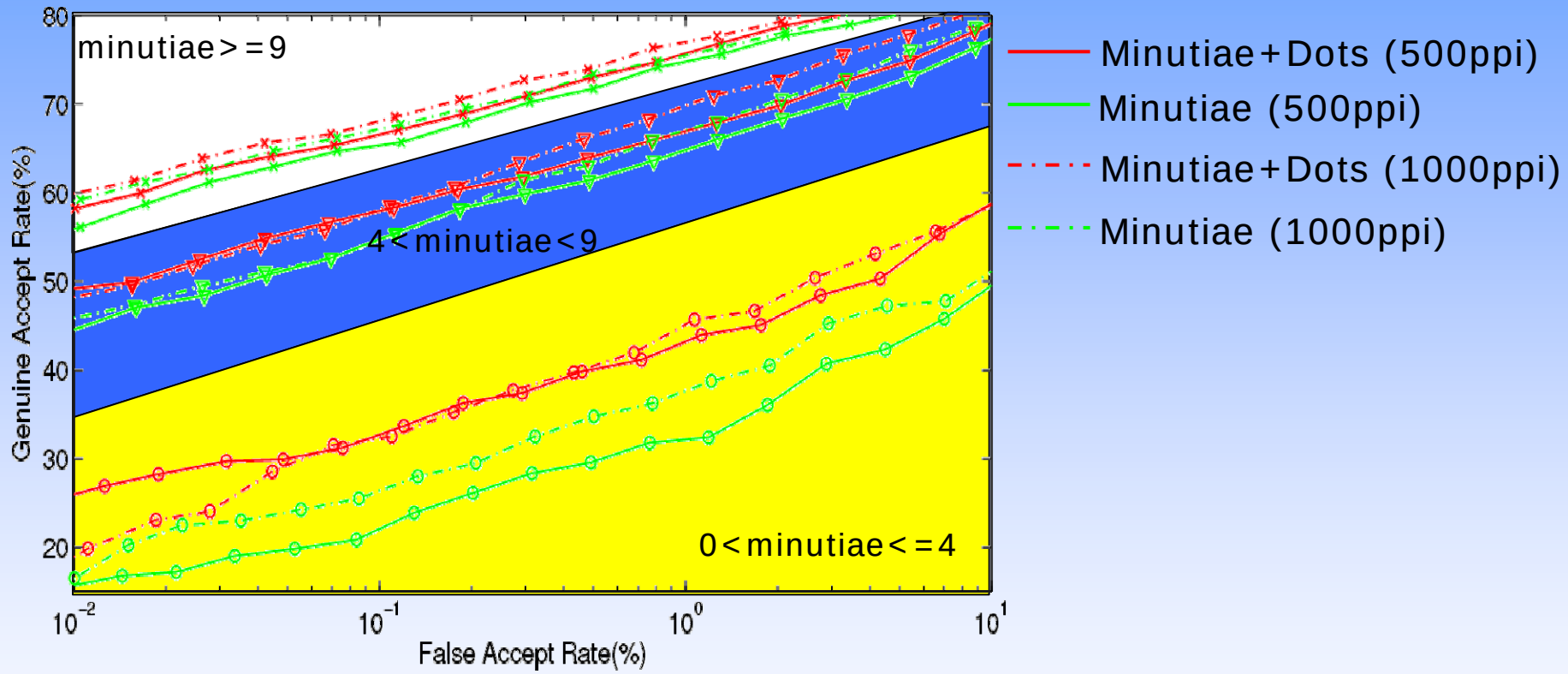
Matching Results

Results of partial to flat matching (MSU database)



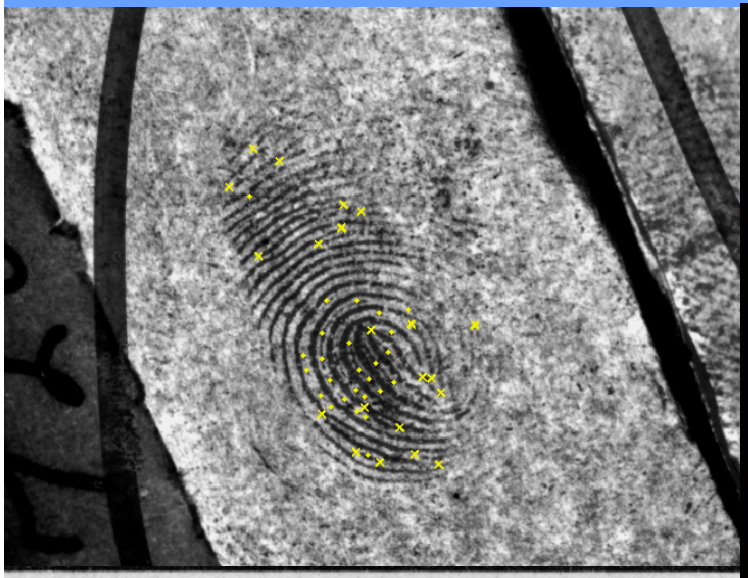
Matching Results

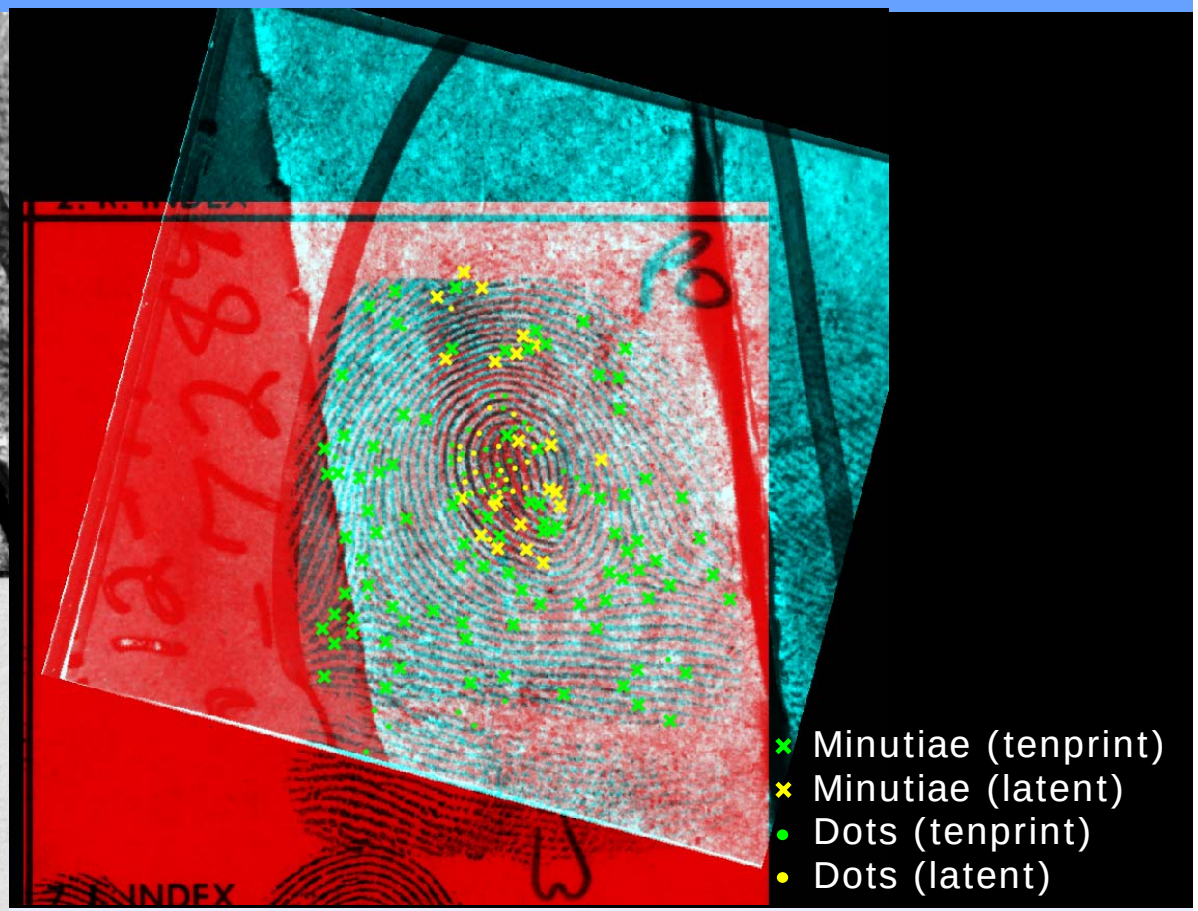
Results of (Cropped) partial to roll matching (NIST SD30 database)



- Partial prints divided into 3 groups based on the no. of minutiae
- Significance of utilizing dots/incipients increases as the no. of minutiae present in partial prints decreases
- 500ppi seems adequate for dots/incipients extraction

Latent Matching Example (NIST SD 27)



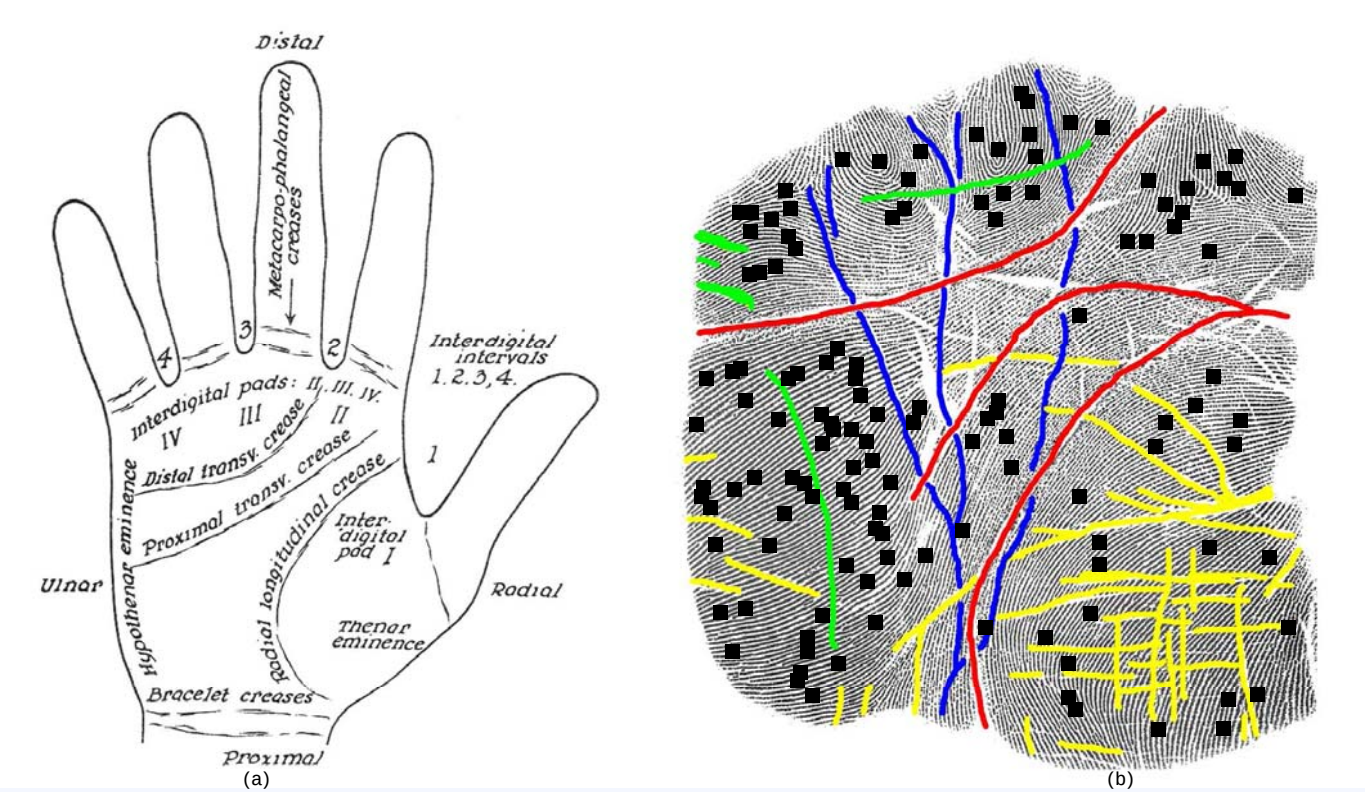


features	match points (Neurotechnologija)	score (Neurotechnologija)
minutiae	10	65
minutiae+dots	45	157

Latent Palmprint Matching

The evidential value of palmprints is clear from the following statistic:

- 25% of all crime scenes contain only latent palmprints
- 30% of the latents recovered from crime scenes are of palms



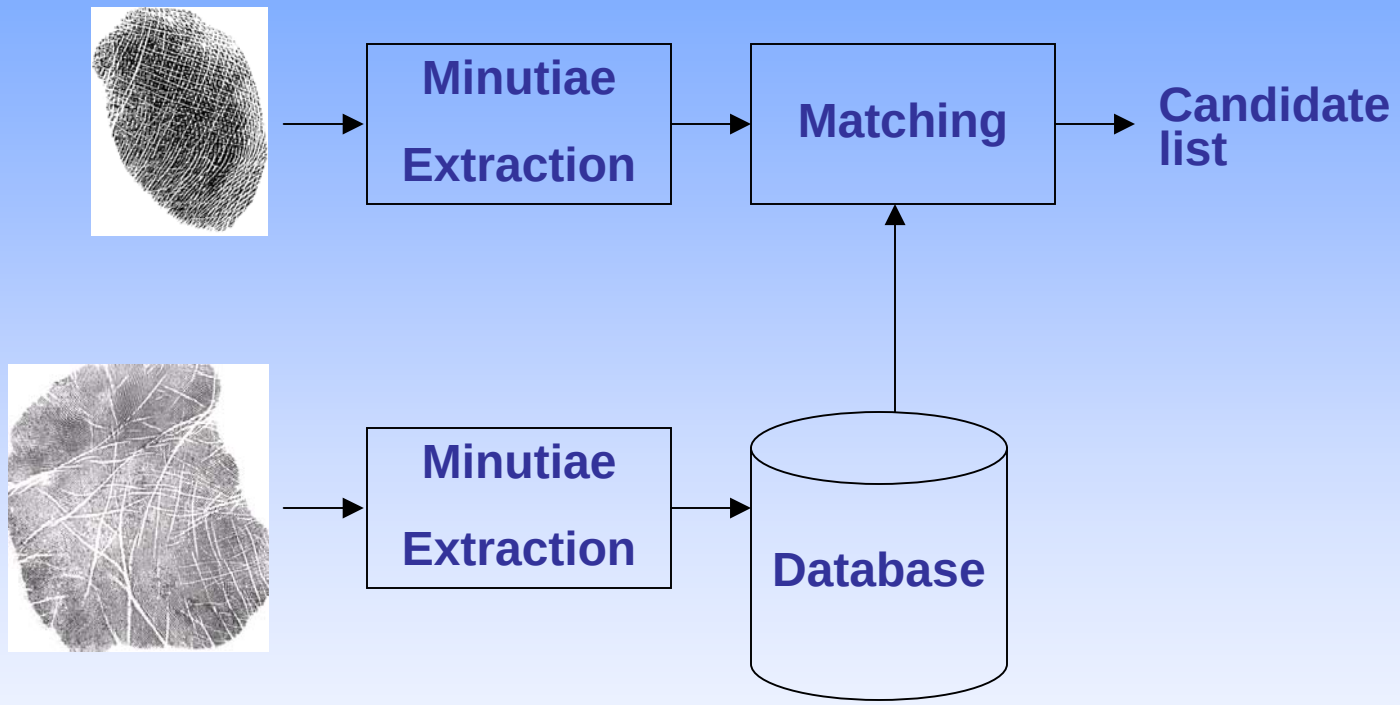
Palmar physiology, (a) Anatomical landmarks for the palm [3], (b) Main groups of palmar flexion creases (major flexion creases → red, minor flexion creases → green, minor finger creases → blue, secondary creases → yellow) and minutiae, → magenta

[1] *http://www.businesswire.com*, El Paso police installs Sagem Morpho Palmprint System, Business Wire, 2002.
[2] S. K. Dewan, W. Elementary, "Scan a Palm, Find a Clue", The New York Times, November 2003.
[3] H. Cummins and M. Midlo, "Finger Prints, Palms and Soles: An Introduction To Dermatoglyphics," Dover Publications, New York, 1961.

Palmprint Research @ MSU

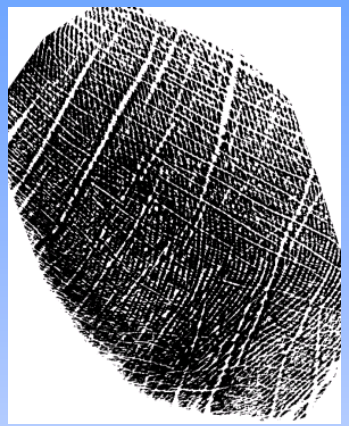
- Automatic feature extraction in latents
- Use minutiaCode in matching
- Extended features
- Hand type, orientation and region determination

Matching System



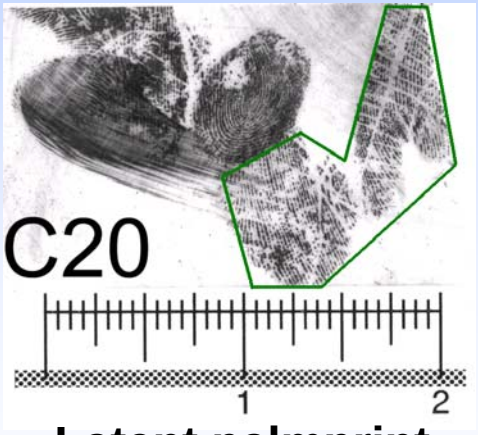
No. of minutiae in a full print = 800; average no. of minutiae in a latent = 150

Databases

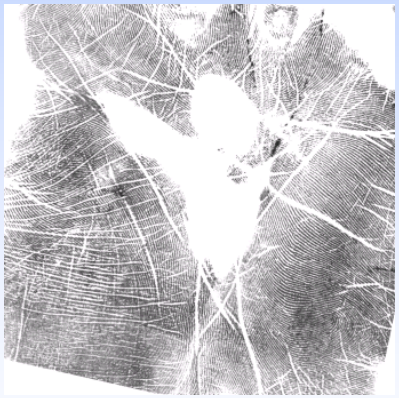


Live-scan partial palmprint
1000x1000 pixels

Ink full palmprint
2000x2000 pixels



Latent palmprint
800x800 pixels

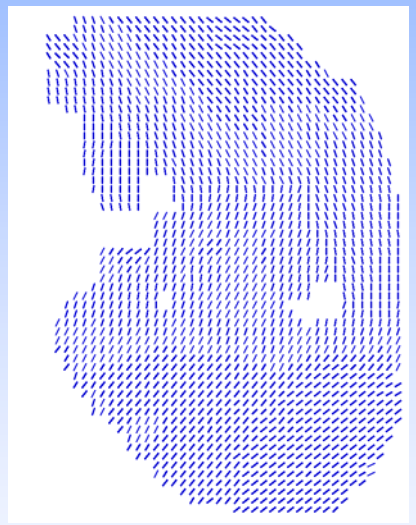


Live-scan full palmprint
2000x2000 pixels

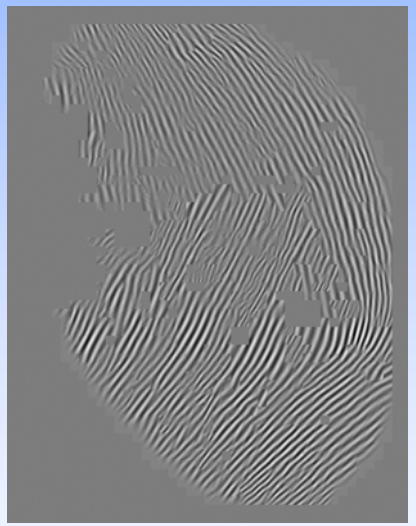
Ridge Extraction

- Estimate local ridge direction and frequency
- Use the directional field for image enhancement
- Binarize, thin and extract ridge and minutiae
- Ridge and minutia validation

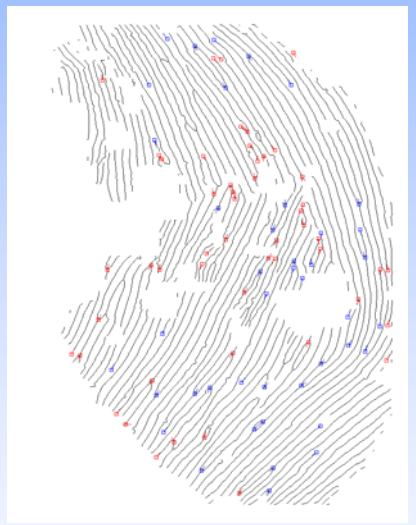
Thenar region



Direction field



Enhanced image

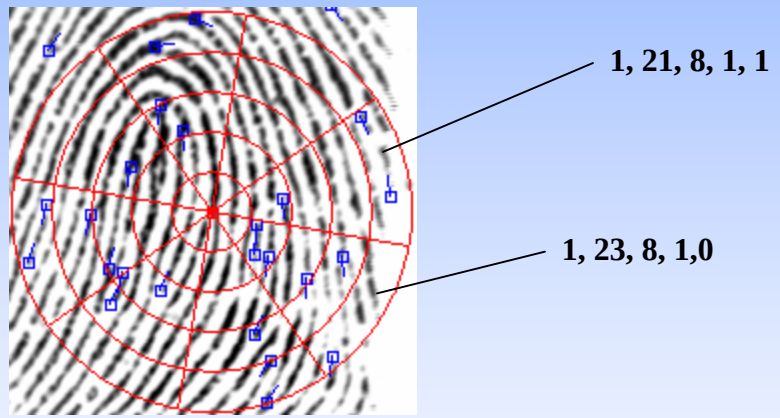


Ridge & minutiae

Thenar is the most difficult region due to a large number ***of creases***

Latent-to-full Matching

- Compute similarity between minutiae based on a new descriptor: MinutiaCode
- Align palmprints according to the most similar minutiae pair
- Find additional matching minutiae using greedy strategy



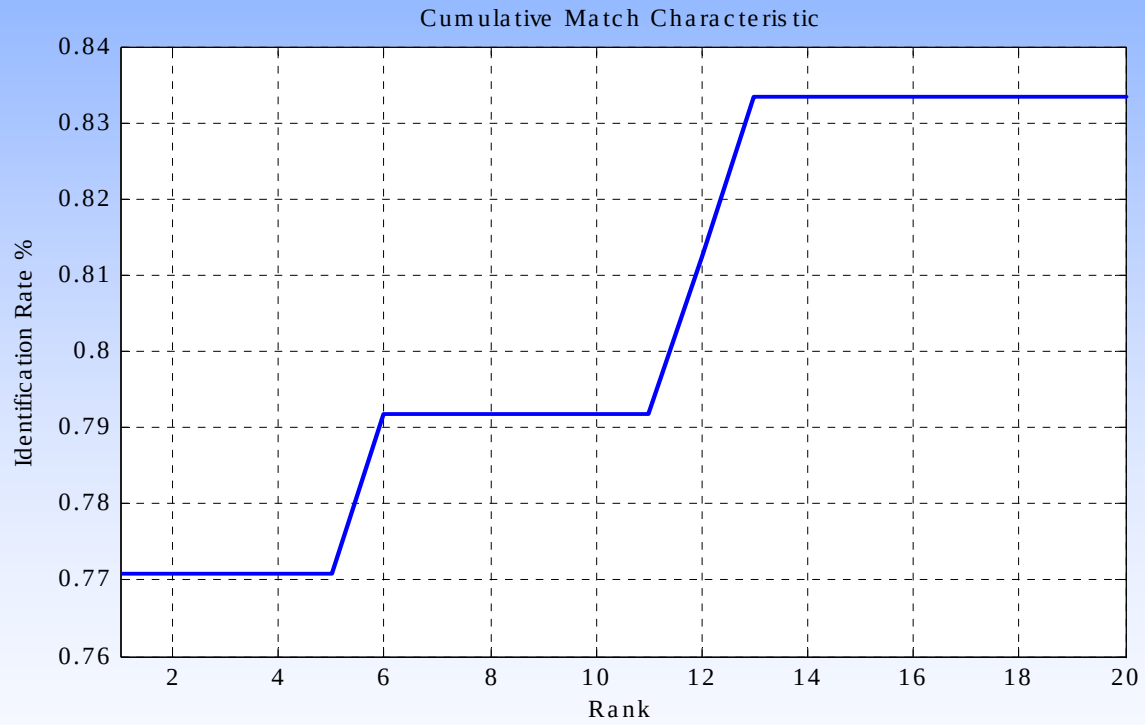
40 sectors around each minutiae; ***MinutiaCode*** is a 200-dimensional vector

Features in each sector of MinutiaCode:

1. ROI flag (1: foreground, 0: background),
2. ridge orientation
3. ridge period
4. number of minutiae with same direction
5. number of minutiae with opposite direction

Latent Matching Results

- Latents have arbitrary rotation in [-180,180]
- Resolution is 400 ppi
- Multiple prints overlap in a single latent
- Quality of a large number of full prints is poor

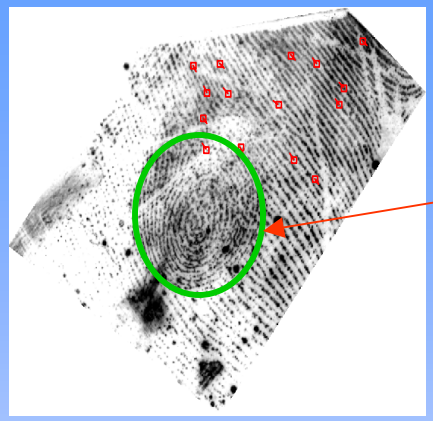


0.36 sec/match

Slower than live-scan partial due to arbitrary rotation

48 latents against 2,136 full prints (36 mated prints of latents + 100 mated prints of live-scan partials + 2,000 single prints)

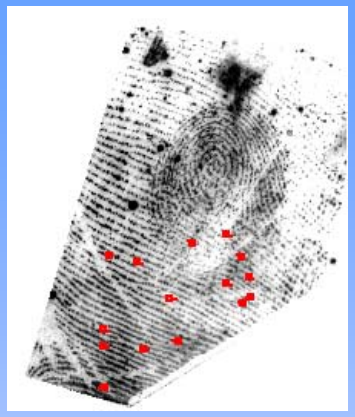
Successful Match for Latent Print



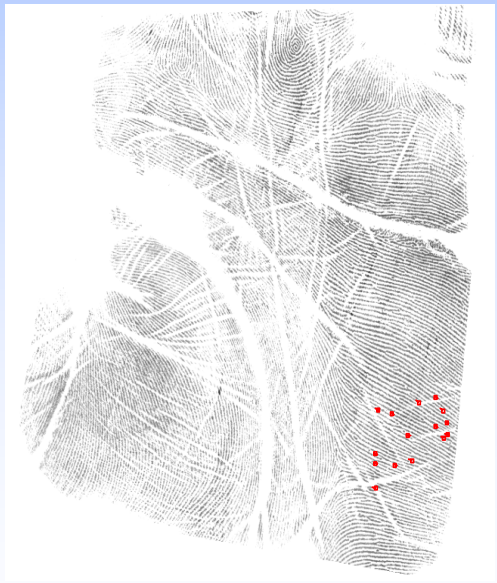
Overlapped fingerprint

180 degree rotation

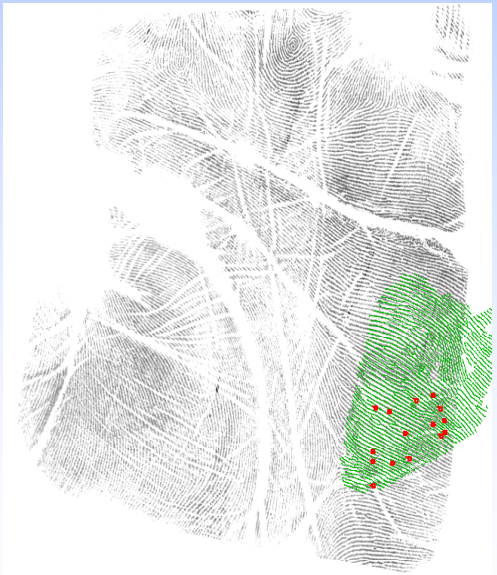
Latent with matching minutiae overlaid



Aligned Latent

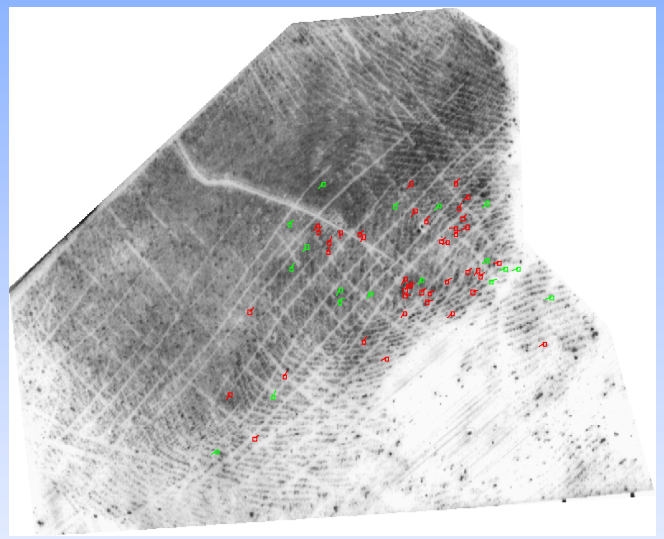


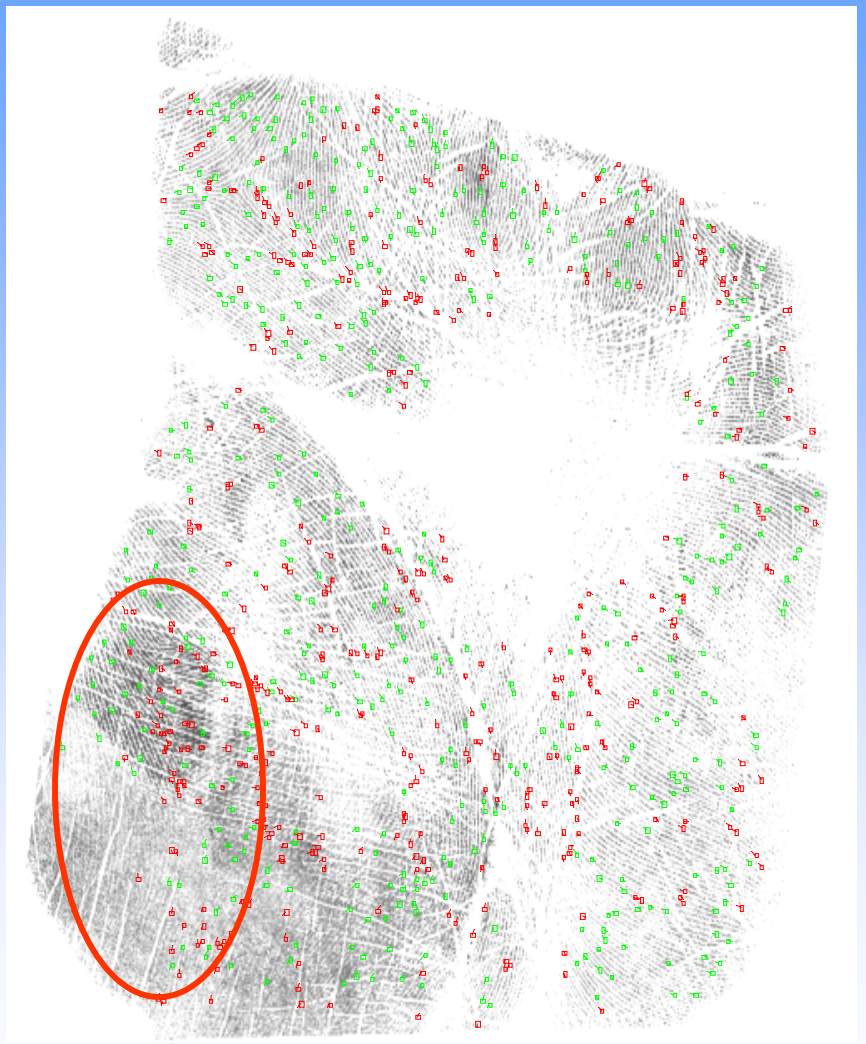
Full print with matching minutiae overlaid



Full print with latent overlaid

Unsuccessful Match for Latent print





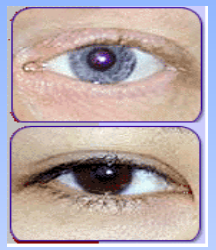
Both images are of poor quality

Soft Biometrics

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

Ethnicity, Skin Color, Hair color
(Sub-Saharan African, Indian, Southern European, and Northwest European)

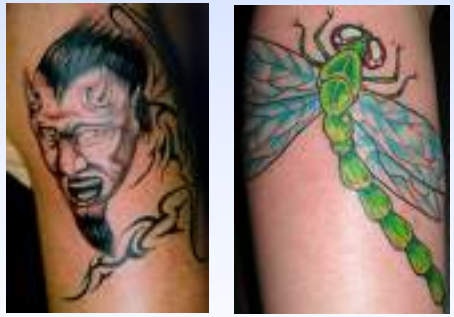
Height



Eye color

Scars

Marks



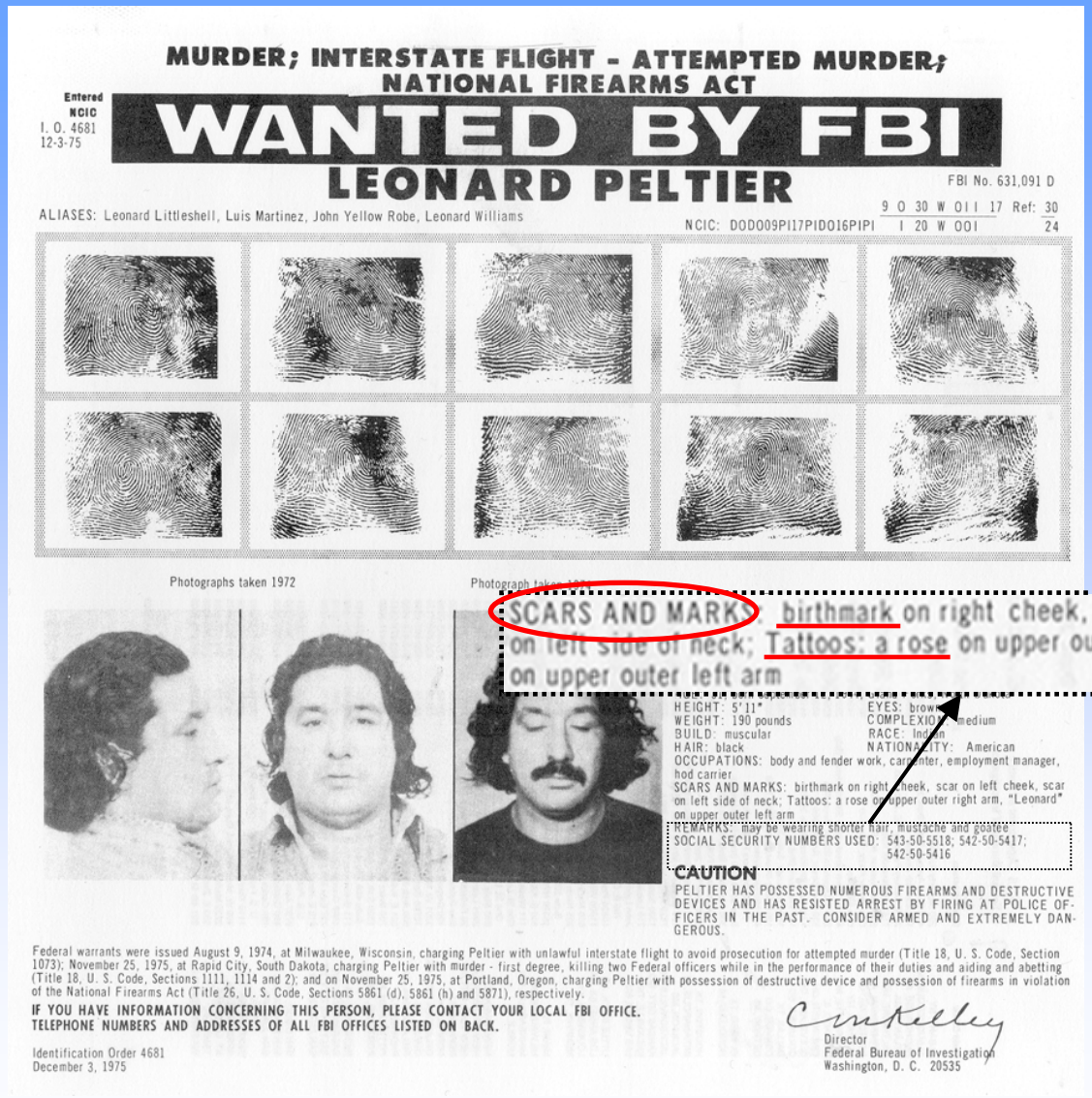
Tattoos

Scars, Marks and Tattoos (SMT)

- Imprints on the skin useful for identifying a suspect or a victim

- Summary of a 2003 online Harris poll:
  - 16% of the adults in the US have at least one tattoo
  - The highest incidence was found among Americans age 25 to 29 years (36%) and 30 to 39 years (28%)

FBI Booking card



MURDER; INTERSTATE FLIGHT - ATTEMPTED MURDER; NATIONAL FIREARMS ACT

Entered NCIC I. O. 4681 12-3-75

WANTED BY FBI

LEONARD PELTIER

FBI No. 631,091 D

ALIASES: Leonard Littleshell, Luis Martinez, John Yellow Robe, Leonard Williams

NCIC: DODO09PI17PIDO16PIPI 9 O 30 W O11 17 Ref: 30 I 20 W 001 24

Photographs taken 1972

Photograph taken 1974

SCARS AND MARKS: birthmark on right cheek, scar on left cheek, scar on left side of neck; Tattoos: a rose on upper outer right arm, "Leonard" on upper outer left arm

HEIGHT: 5'11"
WEIGHT: 190 pounds
BUILD: muscular
HAIR: black
EYES: brown
COMPLEXION: medium
RACE: Indian
NATIONALITY: American

OCCUPATIONS: body and fender work, carpenter, employment manager, hod carrier

SCARS AND MARKS: birthmark on right cheek, scar on left cheek, scar on left side of neck; Tattoos: a rose on upper outer right arm, "Leonard" on upper outer left arm

REMARKS: may be wearing shorter hair, mustache and goatee

SOCIAL SECURITY NUMBERS USED: 543-50-5518; 542-50-5417; 542-50-5416

CAUTION

PELTIER HAS POSSESSED NUMEROUS FIREARMS AND DESTRUCTIVE DEVICES AND HAS RESISTED ARREST BY FIRING AT POLICE OFFICERS IN THE PAST. CONSIDER ARMED AND EXTREMELY DANGEROUS.

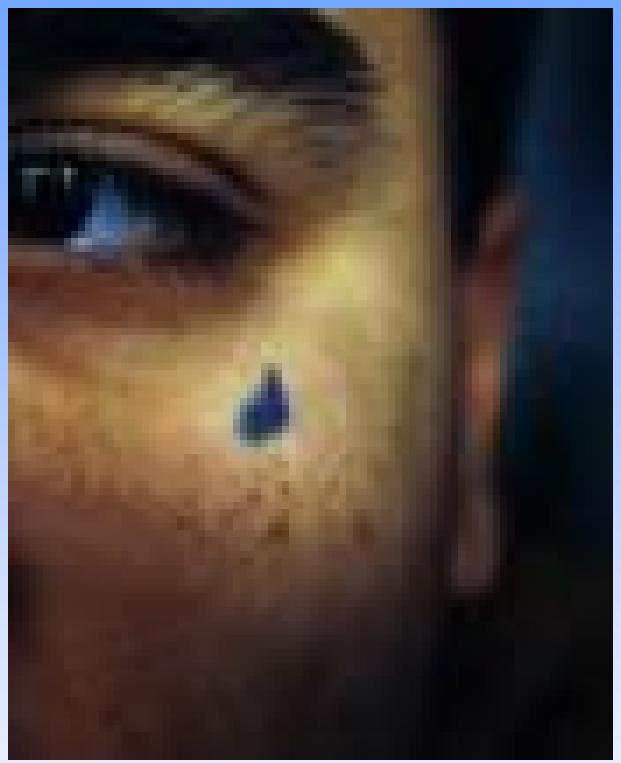
Federal warrants were issued August 9, 1974, at Milwaukee, Wisconsin, charging Peltier with unlawful interstate flight to avoid prosecution for attempted murder (Title 18, U. S. Code, Section 1073); November 25, 1975, at Rapid City, South Dakota, charging Peltier with murder - first degree, killing two Federal officers while in the performance of their duties and aiding and abetting (Title 18, U. S. Code, Sections 1111, 1114 and 2); and on November 25, 1975, at Portland, Oregon, charging Peltier with possession of destructive device and possession of firearms in violation of the National Firearms Act (Title 26, U. S. Code, Sections 5861 (d), 5861 (h) and 5871), respectively.

IF YOU HAVE INFORMATION CONCERNING THIS PERSON, PLEASE CONTACT YOUR LOCAL FBI OFFICE. TELEPHONE NUMBERS AND ADDRESSES OF ALL FBI OFFICES LISTED ON BACK.

Identification Order 4681
December 3, 1975

C. M. Kelley
Director
Federal Bureau of Investigation
Washington, D. C. 20535

Suspect Identification



(a)

(b)

(c)

(a) Teardrop tattoo (person has killed someone or had a friend killed in prison), (b) Texas Syndicate (TS) gang member tattoo, (c) Three dots tattoo found on the prisoner's back of the hand

ANSI/NIST Tattoo Classes

ANSI/NIST ITL 1-2000 Tattoo Classes

Class description	Class code
Human Forms and Features	HUMAN
Animals and Animal Features	ANIMAL
Plants	PLANT
Flags	FLAG
Objects	OBJECT
Abstractions	ABSTRACT
Insignias & Symbols	SYMBOL
Other Images	OTHER

ANSI/NIST ITL 1-2000 Animal Tattoo Subclasses

Subclass	Subclass code
Cats & Cat Heads	CAT
Dogs & Dog Heads	DOG
Other Domestic Animals	DOMESTIC
Vicious Animals (Lions, Tigers, etc.)	VICIOUS
Horses (Donkeys, Mules, etc.)	HORSE
Other Wild Animals	WILD
Snakes	SNAKE
Dragons	DRAGON
Birds (Cardinal, Hawk, etc.)	BIRD
Spiders, Bugs, and Insects	INSECT
Abstract Animals	ABSTRACT
Animal Parts	PARTS
Miscellaneous Animal Forms	MANIMAL


Human


Animal


Plant


Flag


Object


Abstract


Symbol


Other

Tattoo Identification in Forensics

- Current systems retrieve tattoo images based on human-assigned class labels with text query
- Limited number of categories and large intra-class variability makes it difficult to label a tattoo
- The same tattoo image can have multiple labels

Six tattoos in the FLAG category

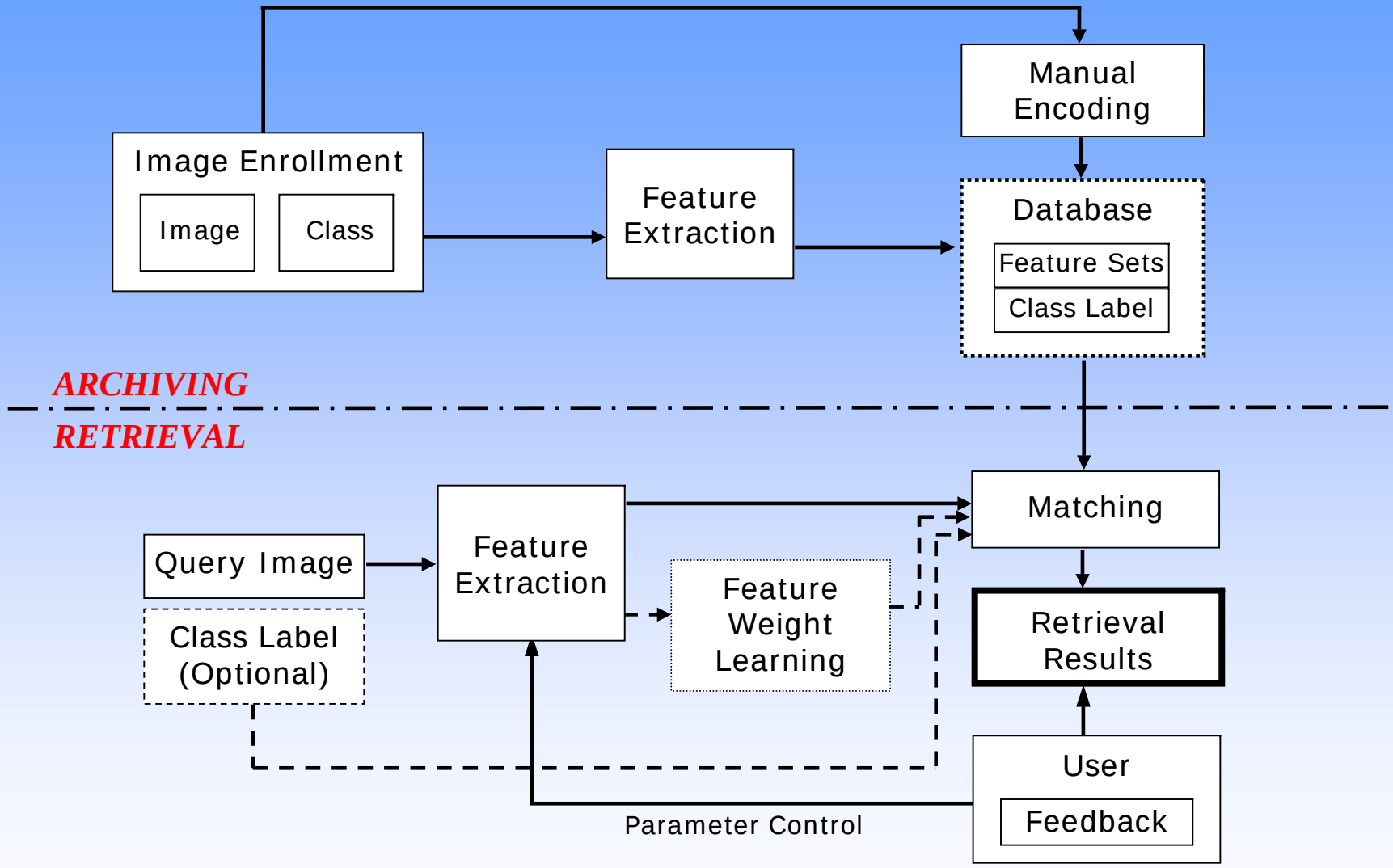
Content-based Tattoo Image Retrieval

- Given an image query and an optional associated class label, retrieve the top-N most similar images from the database
- Image query specifies the content of the tattoo pattern

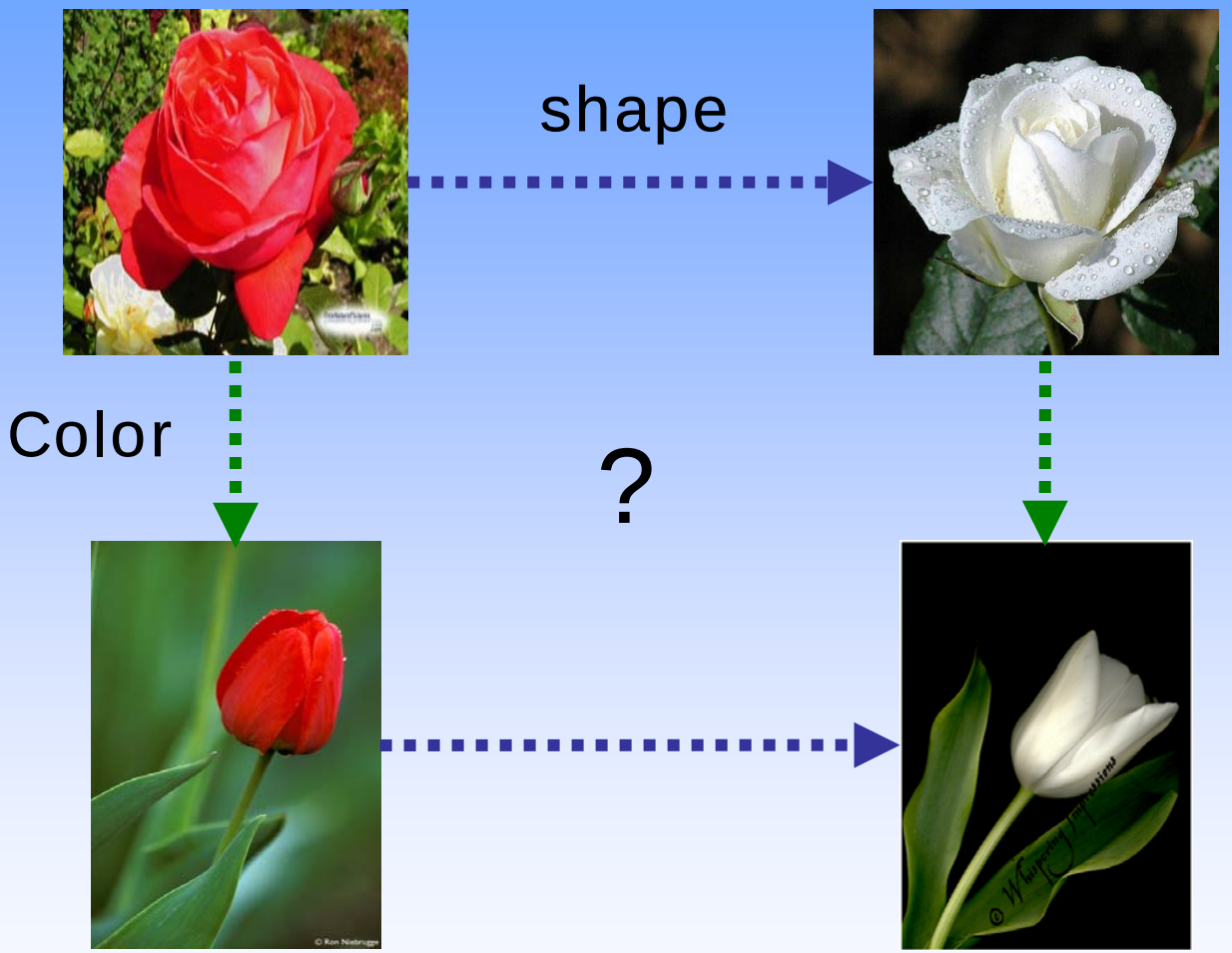
Query

Top-8 most similar tattoos for the query “star” tattoo

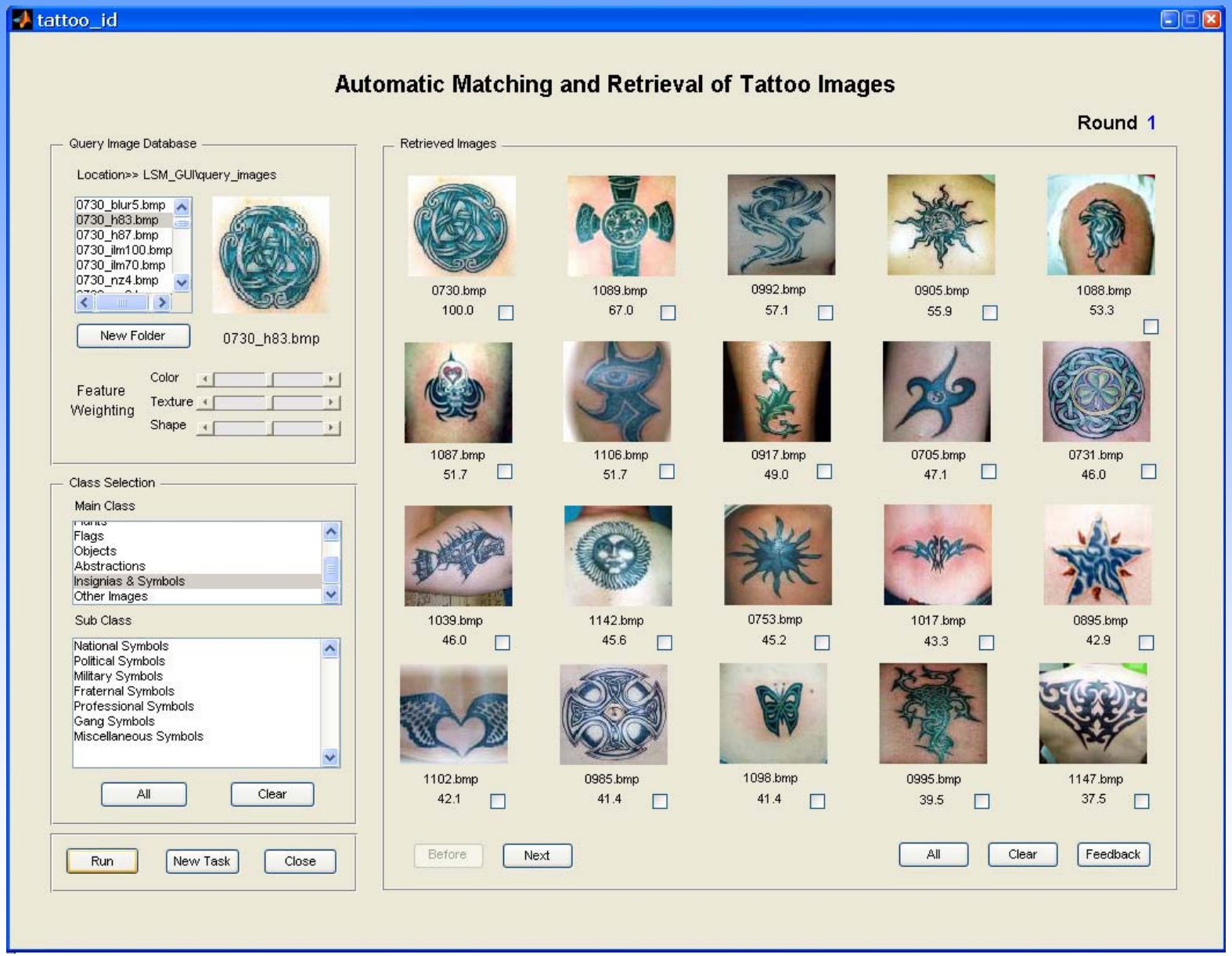
Tattoo-ID System



How to Define Image Similarity



Tattoo-ID System



SMT Database

- 5,300 tattoo images (90x90) downloaded from the Web
  - 4,700 common tattoos and 500 gang tattoos
  - 100 tattoos captured from a subject's arm under different imaging conditions

Human Animal Plant Flag Object Abstract Symbol Other

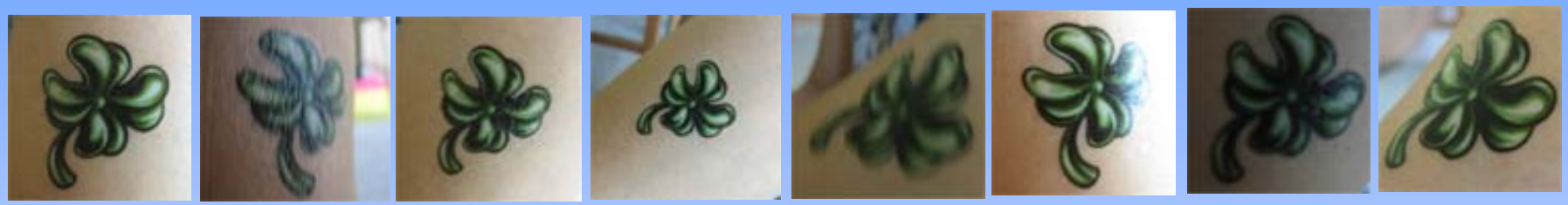
(a) (b) (c) (d) (e) (f) (g)

Gang Tattoos: (a) and (b) Ambrose, (c) Adidas boys, (d) Brazers, (e) Latin Kings, (f) Family Stones, (g) Insane Deuces (From GangInk.com)

- 250 scars and marks images from the Web

Image Variations

- Tattoo images are often captured under non-ideal conditions (e.g., by a surveillance video camera)



"PLANT" tattoo images captured under different imaging conditions

- Image deformations classified as: affine transformation, blurring, changes in illumination, color, aspect ratio and rotation

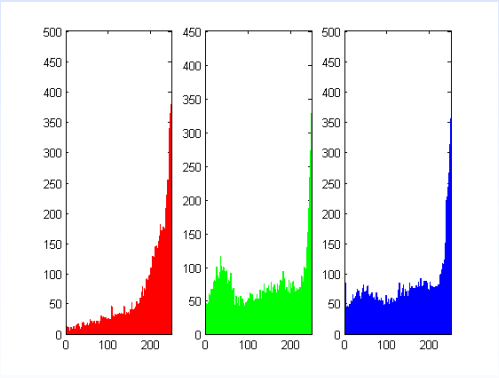
(a) (b) (c) (d) (e) (f) (g)

(a) original; variations due to (b) blurring, (c) illumination, (d) color component changes, (e) affine transformation, (f) aspect ratio change, and (g) rotation

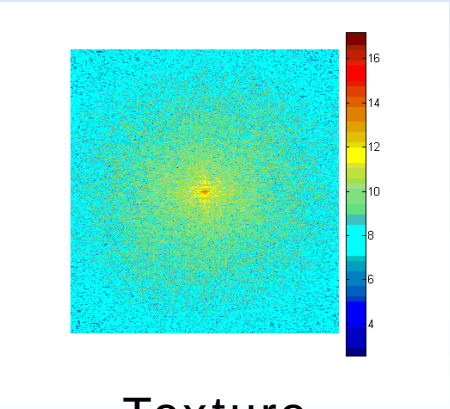
Low-level Image Features

- Color features
  - Color histogram: root-mean-square distance among RGB values
  - Color correlogram: spatial correlation of pairs of colors
- Shape features
  - Seven 2nd and 3rd order invariant moment features are extracted from grayscale and gradient image
- Texture
  - Edge direction coherence vector (EDCV): ratio of coherent versus non-coherent edge pixels

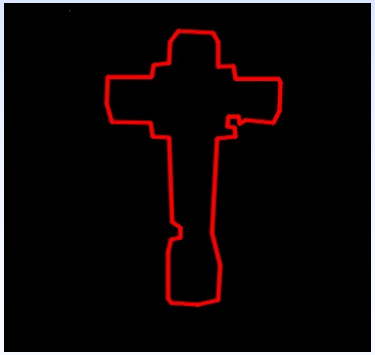
Sample Image



Color Histogram



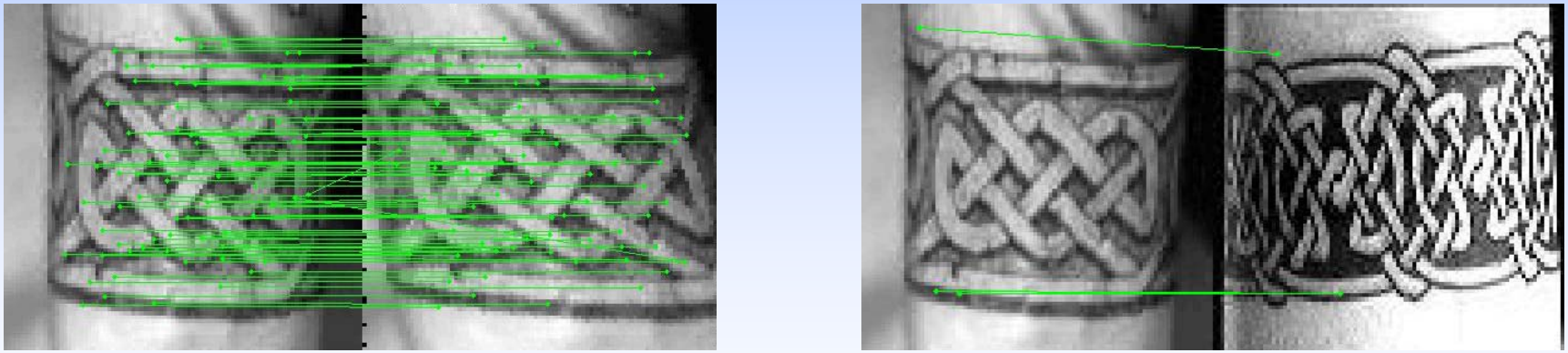
Texture



Shape

SIFT Keypoint Matching

Examples of SIFT keypoints



(a) 87 (b) 3

Numbers of matching points between (a) similar and (b) different images

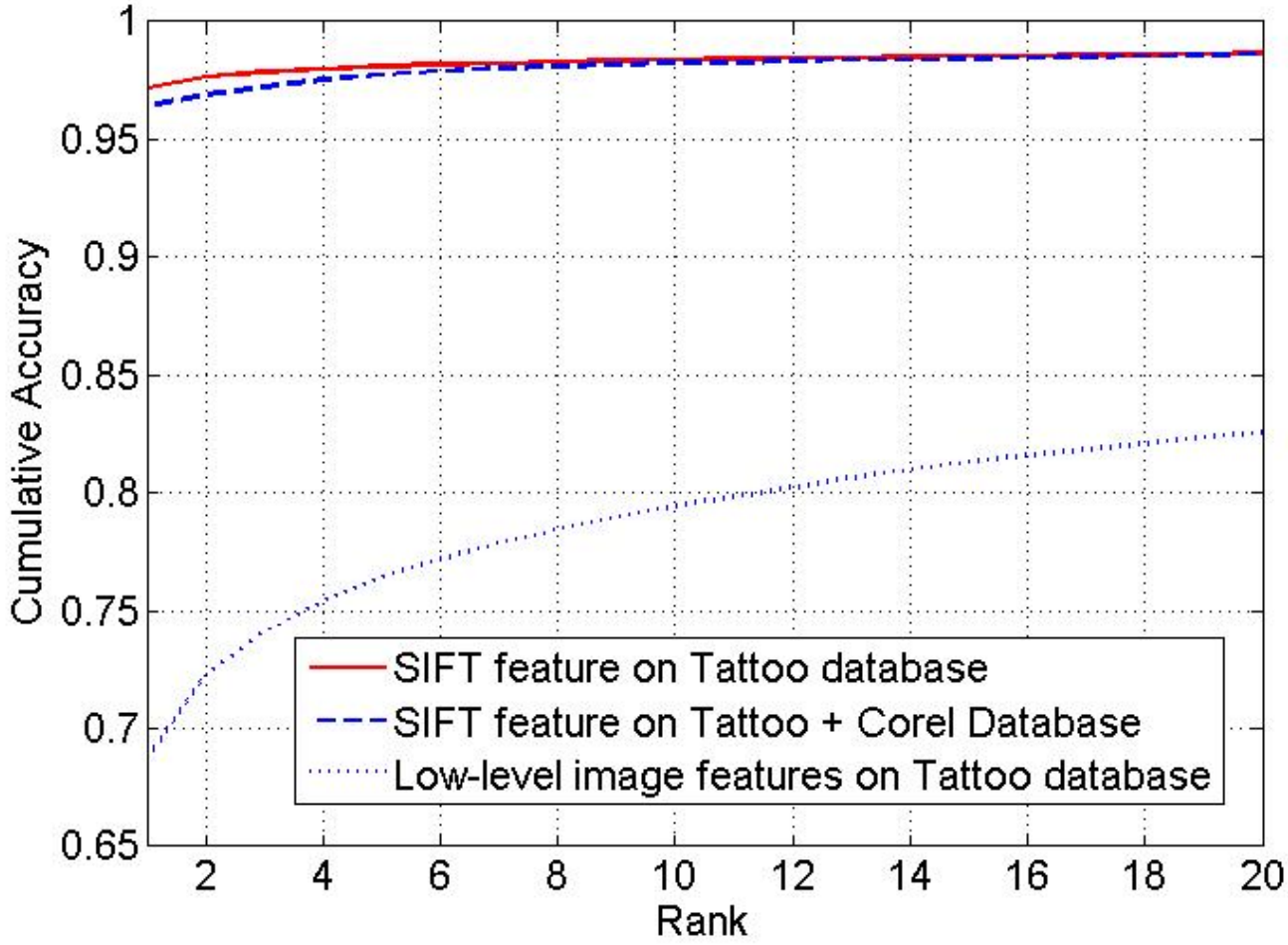
Experiments

- Transformed image queries against a gallery of original images

	No. of queries	gallery size
Tattoo Retrieval	104,460	5,223 and 10,223
Scar/Mark Retrieval	5,000	250

- Rank-1 accuracy is 97.2% for tattoos (96.6% on the enlarged gallery with COREL images) and 87.9% for scars & marks
- Retrieval time:
  - Feature extraction: 0.0005 sec/image
  - Matching per image pair: 0.005 sec

Experimental Results



CMC Curve for tattoo image retrieval

Retrieval Examples

Operational Tattoo Database

- Database (100,000 tattoo images) from Michigan Forensics Lab

Future Work

- Image enhancement
- Investigate image features for complex & large tattoos
- Develop automatic image annotation technique
- Feedback to improve annotation/retrieval performance
- Indexing

Current Tattoo Database

Tattoo Database for Future Work

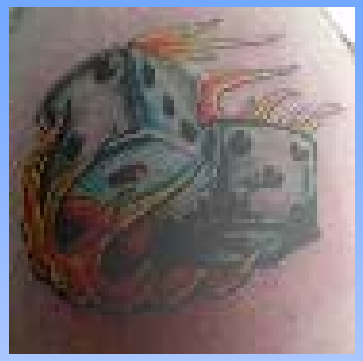
Image Enhancement

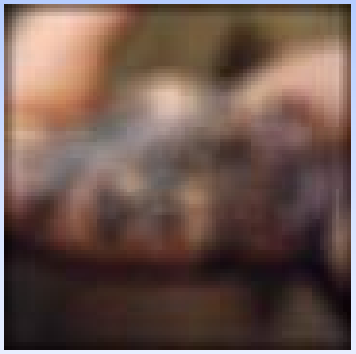
- Image enhancement is needed to improve retrieval performance

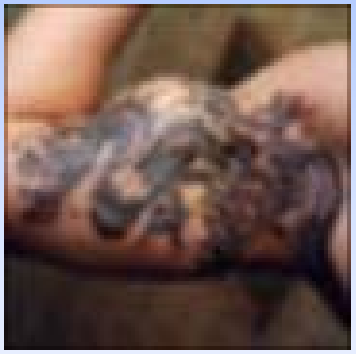

(a) 542

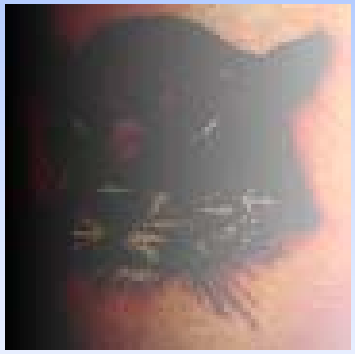

(a') 1

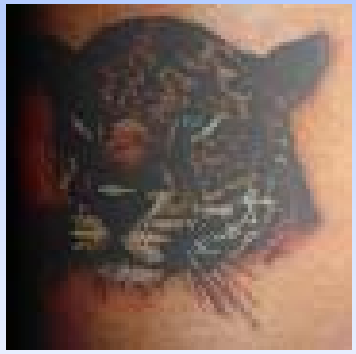

(b) 78


(b') 12


(c) 2342


(c') 172


(d) 1942


(d') 8

(a), (b), (c), (d) show examples of severely degraded images and the ranks at which correct retrievals were found. The retrieval performance is improved after images are manually enhanced in (a'), (b'), (c'), (d')

Automatic Face Recognition

- Authentication/Verification (1:1 matching)

- Face Identification/recognition (1:N matching)

Why Face?

- Face is the most common biometric used by humans
- Identification at a distance
- Easy to capture from low-cost cameras
- Non-contact acquisition
- Covert data acquisition (surveillance cameras)
- Legacy database (passport, visa and driver license)

Face Identification
on Mobile

http://www.securityatwork.org.uk

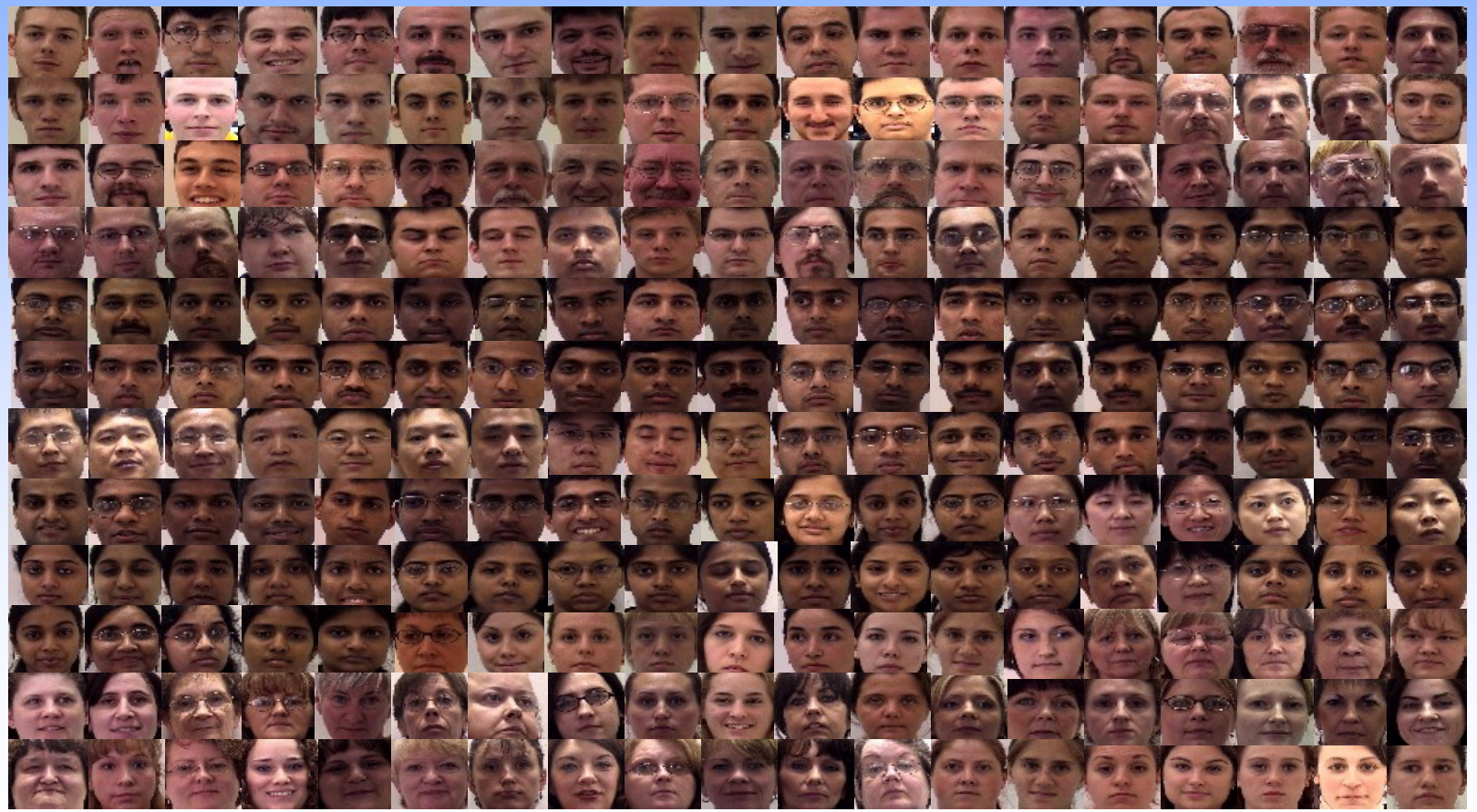
Surveillance video

Legacy Database

http://web.mit.edu/newsoffice/nr/2002/faces

Multiple Enrollments

- Large legacy databases (passports, driver licenses)
- Florida DMV “scrubbed” its database and found ~5,000 duplicates by matching 700K face images against a database of 51M faces (Courtesy, Merkatum)



Challenges

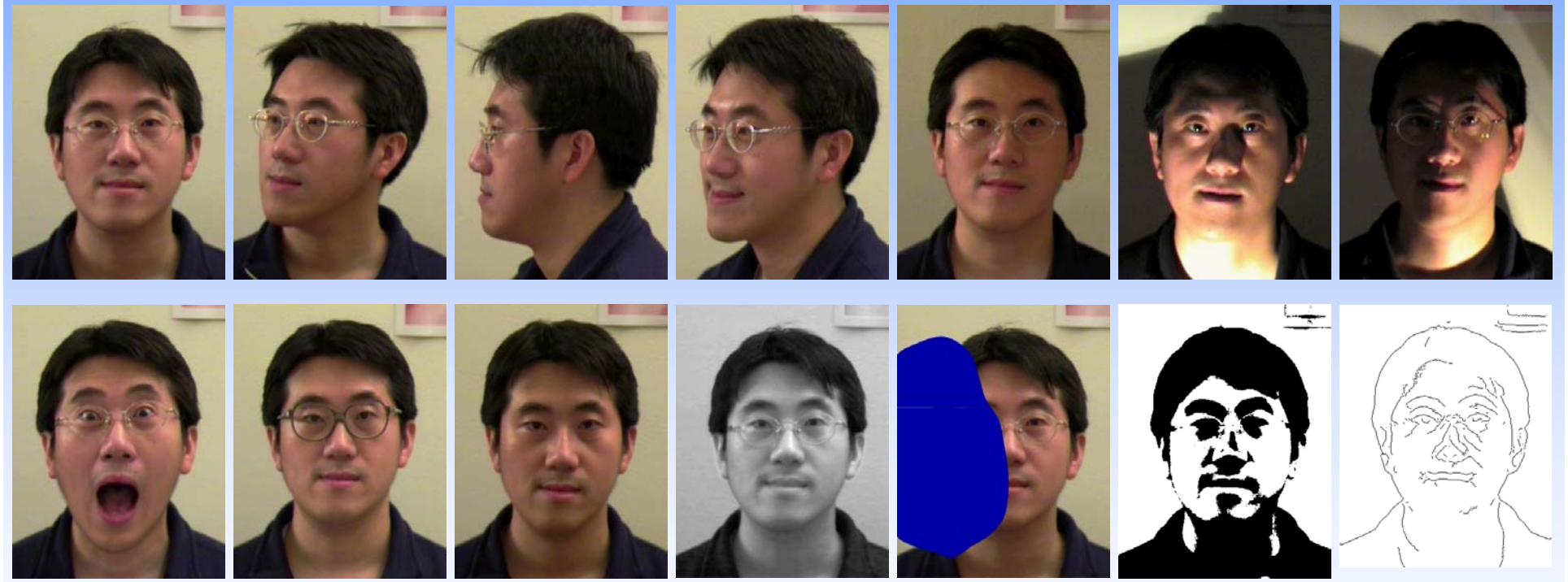
- Automatically locate the face
- Identify similar faces (inter-class similarity)
- Accommodate intra-class variability due to:
  - head pose
  - illumination conditions
  - expressions
  - facial accessories
  - aging effects
- Cartoon faces

Face Detection

*Theo Pavlidis, http://home.att.net/~t.pavlidis/comphumans/comphuman.htm

Intra-class Variability

- Faces with intra-subject variations in pose, illumination, expression, accessories, color, occlusions, and brightness



Inter-class Similarity

- Different persons may have very similar appearance

www.marykateandashley.com

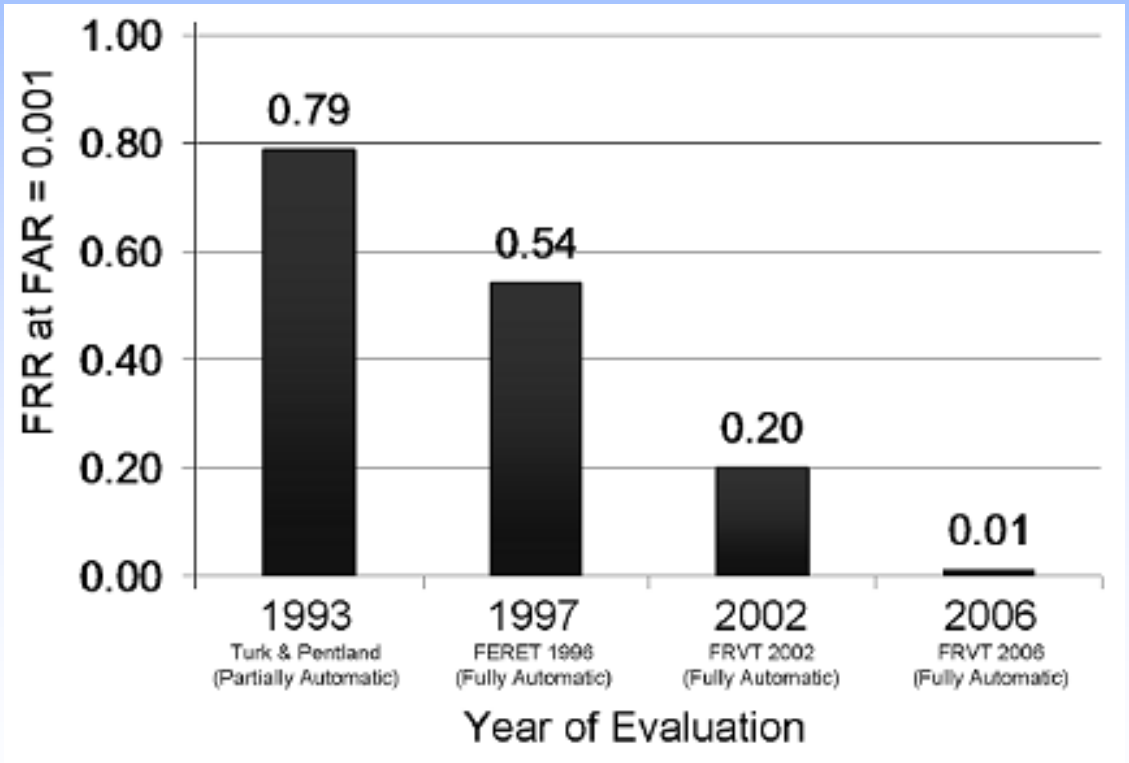
Twins

news.bbc.co.uk/hi/english/in_depth/americas/2000/us_elections

Father and son

State-of-the-Art

- Face Recognition Vendor Test 2006
  - The latest large scale evaluation of face recognition systems
  - Tests have performed on
    - High resolution still imagery (5 to 6 mega-pixels) – 336 subjects
    - Multi-sample still facial imagery (low resolution) – 36,000 subjects
    - 3D facial scans – 330 subjects



Video Surveillance Trial
Mainz Railway Station

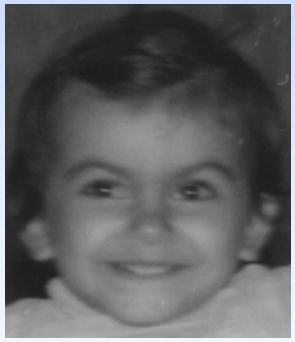
- Performed by German Federal Police (Oct, 06 to Jan 07)
- Purpose: Test Face recognition systems in a real environment of a train station; camera views at escalator & stairs
- Performance: Identification rate of 60% at a FAR of 0.1% based on a gallery (watch list) of 200 enrolled persons

Age Modeling for Face Recognition

- Facial shape and texture change over time
- Current face recognition technologies cannot handle changes due to aging process
- Applications
  - Age estimation: Age specific access control (vending machines)
  - Synthetic aging/de-aging: Missing child

Age 2

Subject 1



Subject 2

Age 18

Subject 1

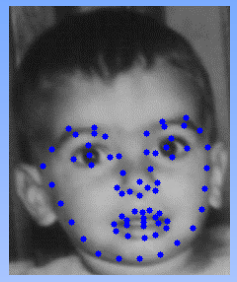
Subject 2

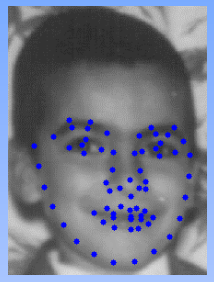
Approach

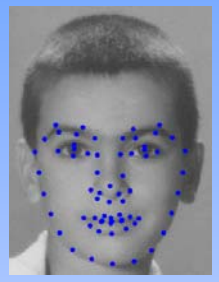
- Build statistical models of face aging
  - Use 3D morphable model to correct pose
  - Modeling is carried out in 3D domain
  - Both shape and texture are modeled
- Goal is to achieve realistic aged/de-aged face images to improve face recognition performance
- Age estimate can be obtained as a byproduct

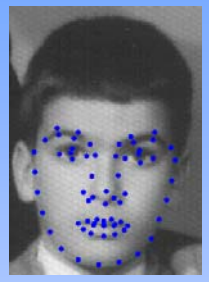
FG-NET Database

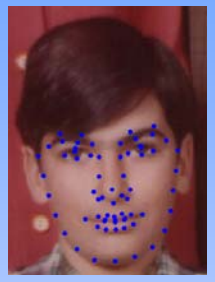
82 subjects with 1002 images (~12/subject) ranging in age from 0-69; variations in pose, expression, illumination & aging

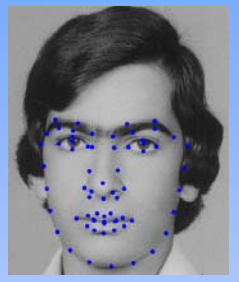

Age 2

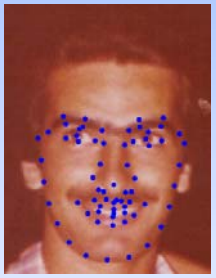

Age 5


Age 8


Age 10

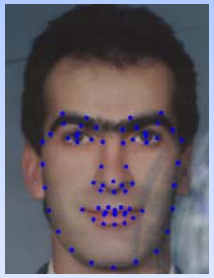

Age 14

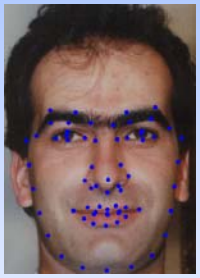

Age 16


Age 18


Age 19


Age 22


Age 28


Age 29


Age 33


Age 40

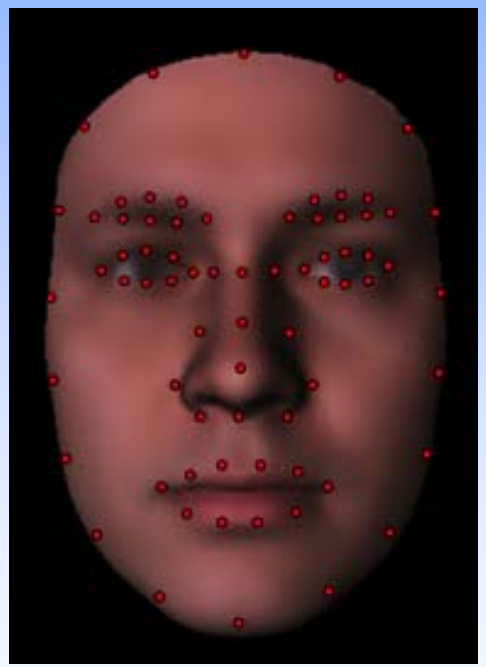

Age 43

Database comes with 68 facial feature points manually marked (facial boundary, eyebrow, eye, nose and mouth)

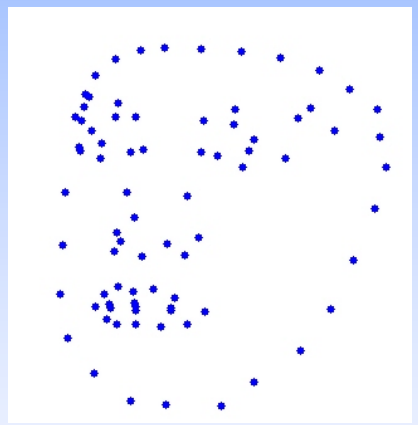
3D Morphable Model

- Morphable model is used for pose correction

3D morphable model



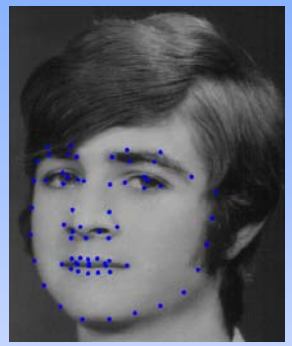
Feature point labeling



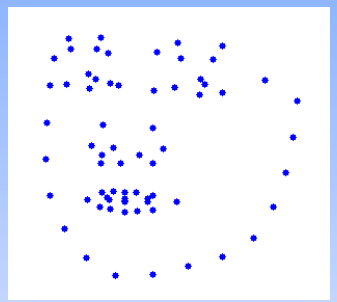
3D morphable model With 81 points

Pose Correction using 3D Model

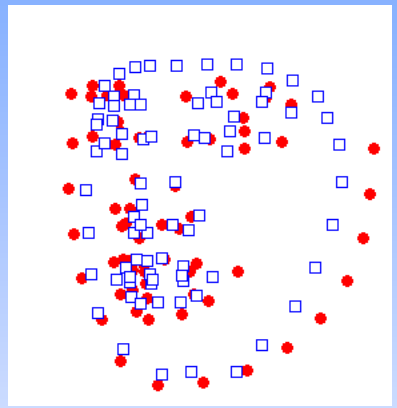
- Frontal shape is obtained by fitting the 3D model to the 2D shape



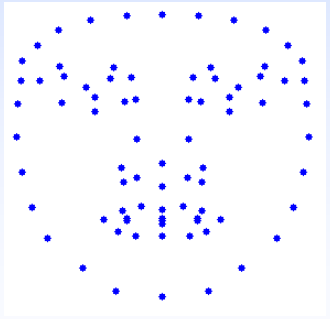
Input Image with feature points



2D points (68 pts)



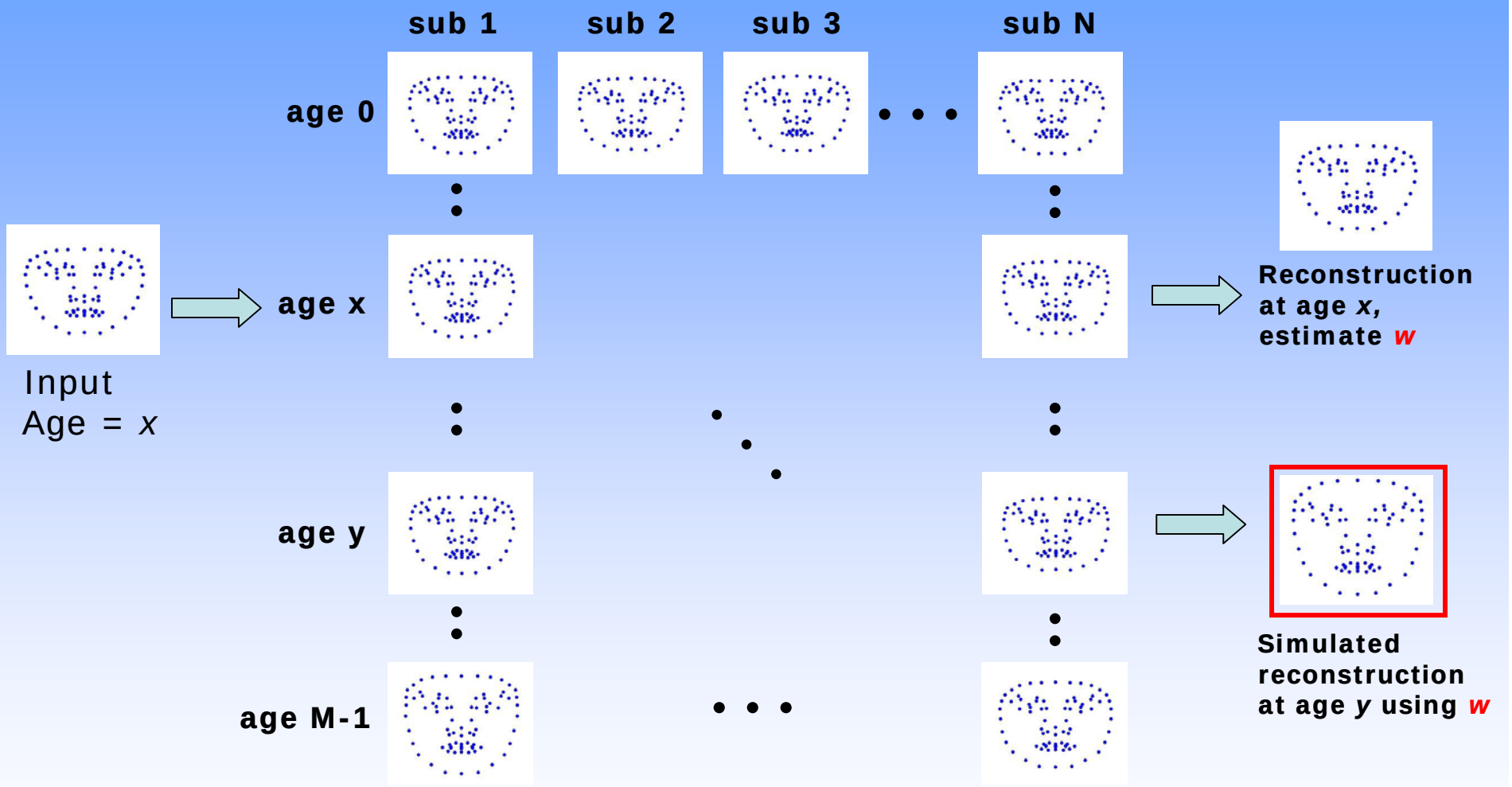
3D model fitting (81 pts)



3D model in frontal view

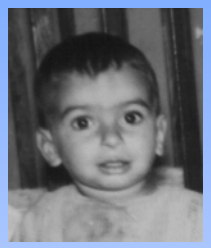
Pose-corrected Texture

Illustrating Age Simulation

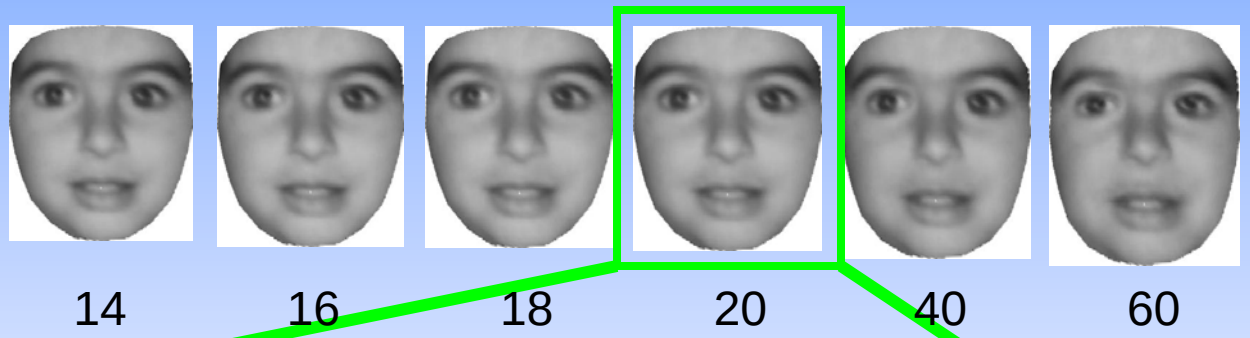


*** Texture simulation follows the same method**

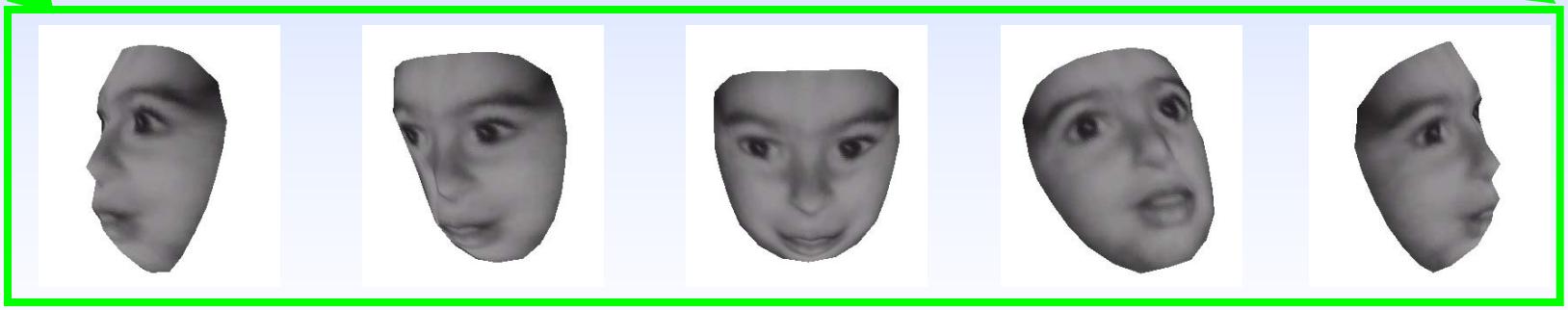
Aging Simulation Example



Input image at age=2



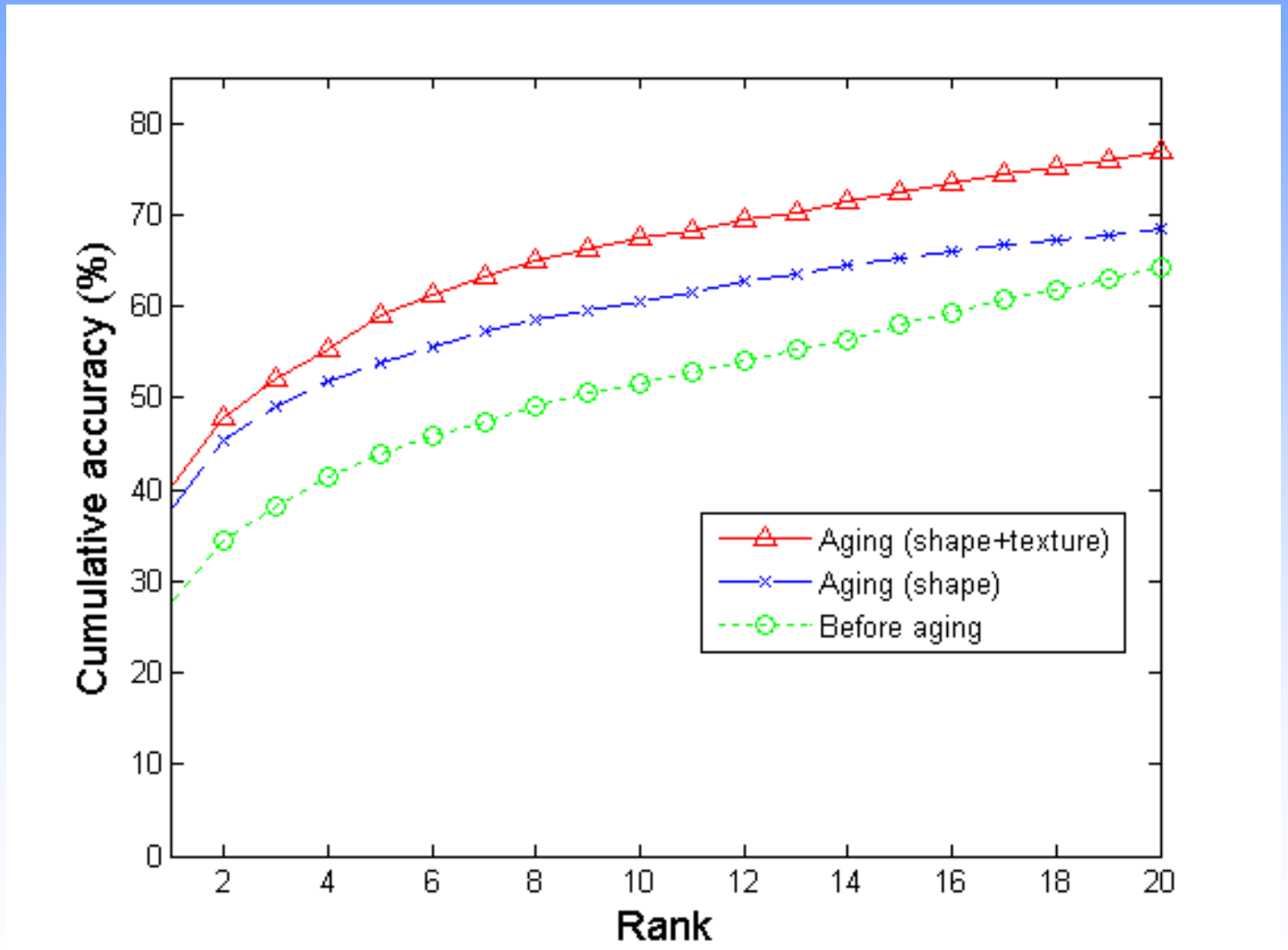
Aging-simulated images from age 0 to 60



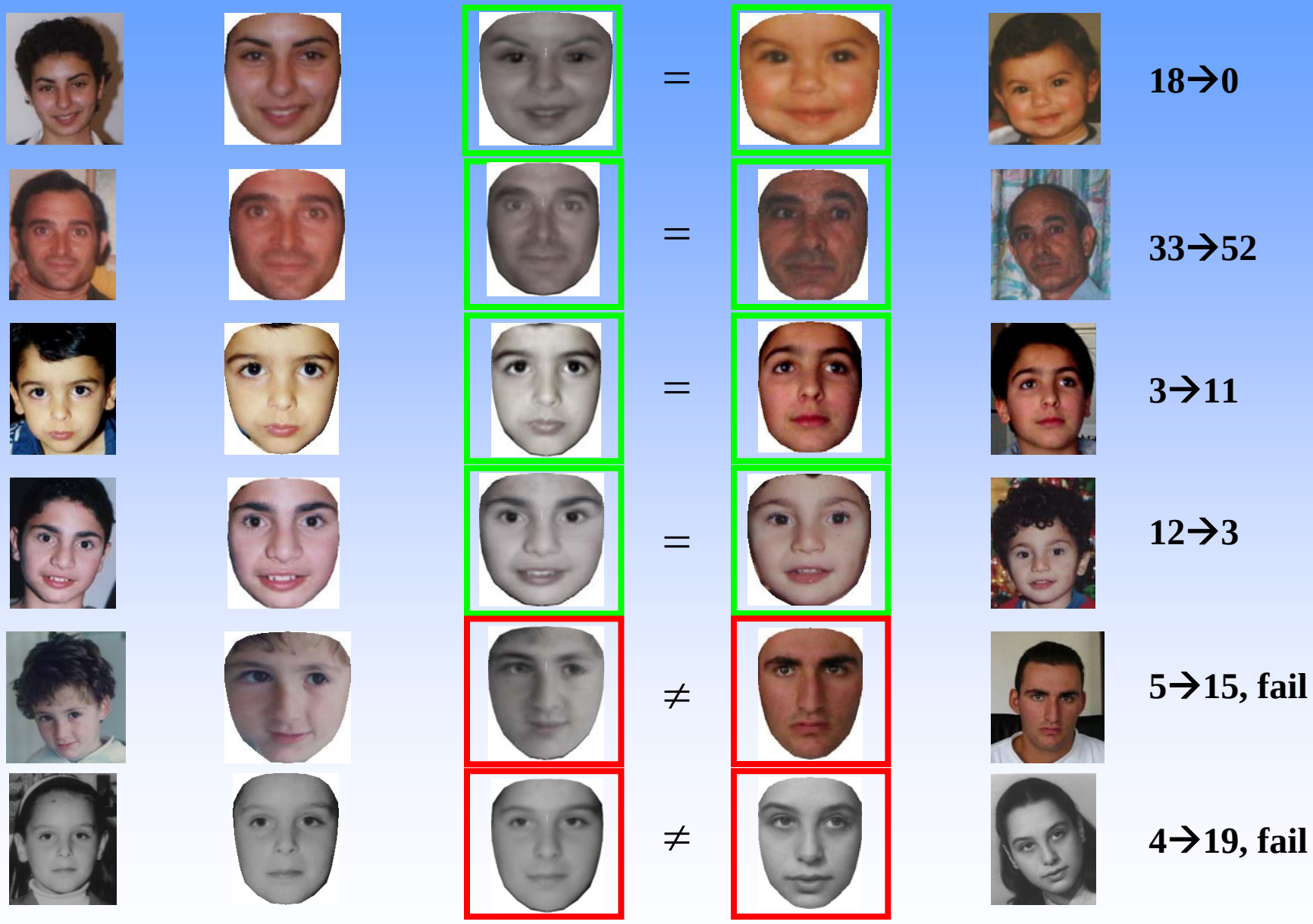
Face images at five different poses from the aging-simulated image at age 20

Experimental Results

Rank-one accuracy improves from 28% to 40.1%. Results are averaged over 82 subjects and 41 different probe and gallery age groups

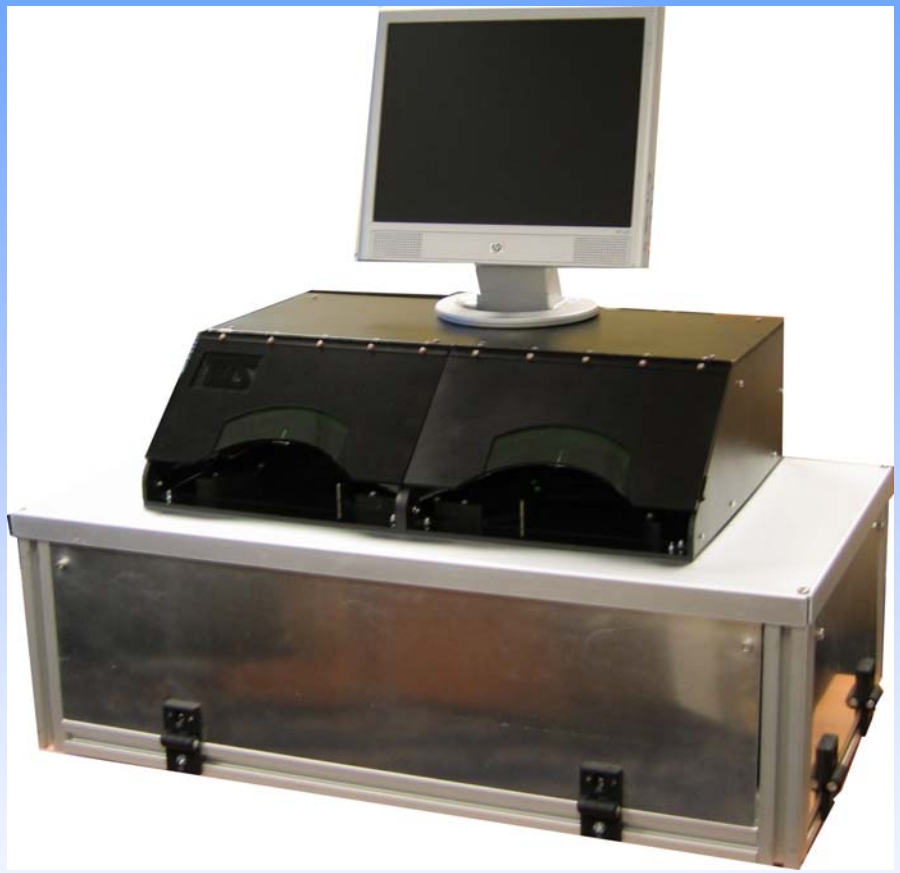


Experimental Results (matching at rank-1)



Touchless Fingerprint Sensors

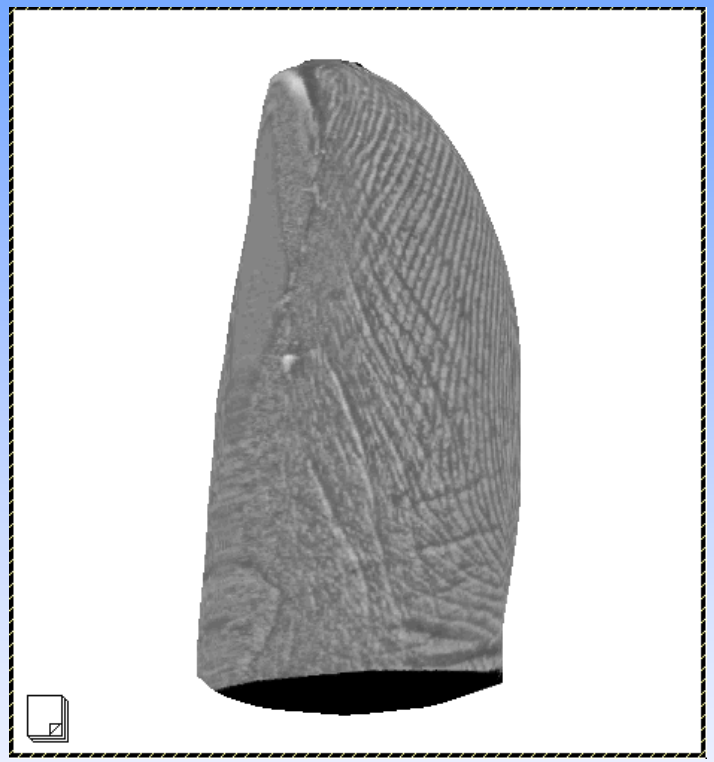
Surround Imager



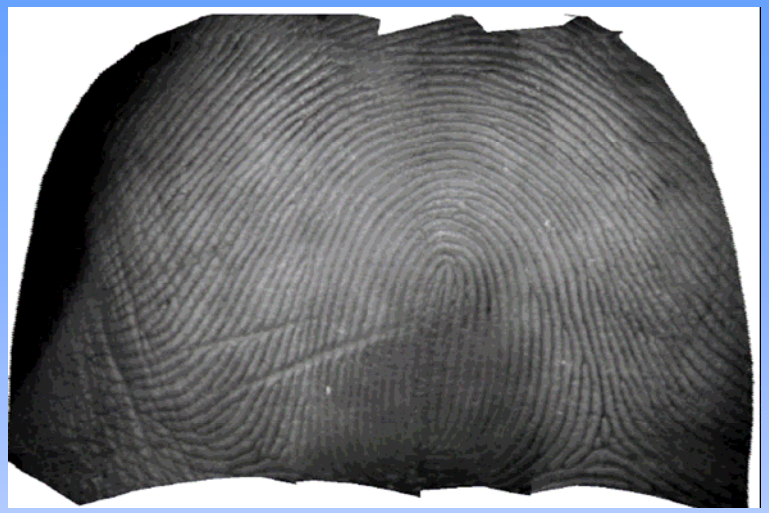
Ten print capture device

NIJ fast fingerprint capture technology initiative; US-VISIT will start capturing 10 fingers as opposed to current 2 fingers (Courtesy TBS, NA)

Interoperability



Touchless 3D image

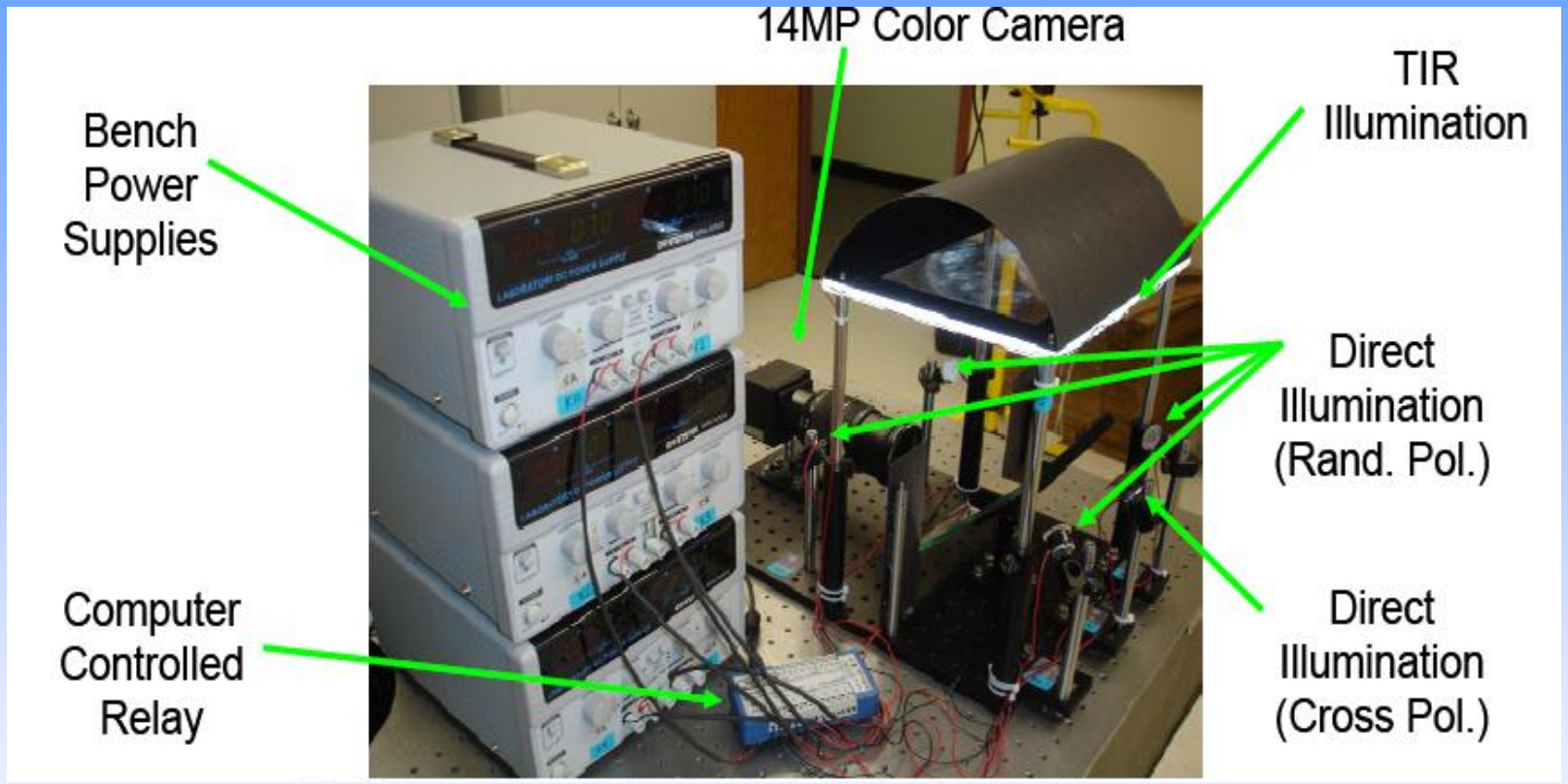


Virtual “rolled” image

Ink on paper

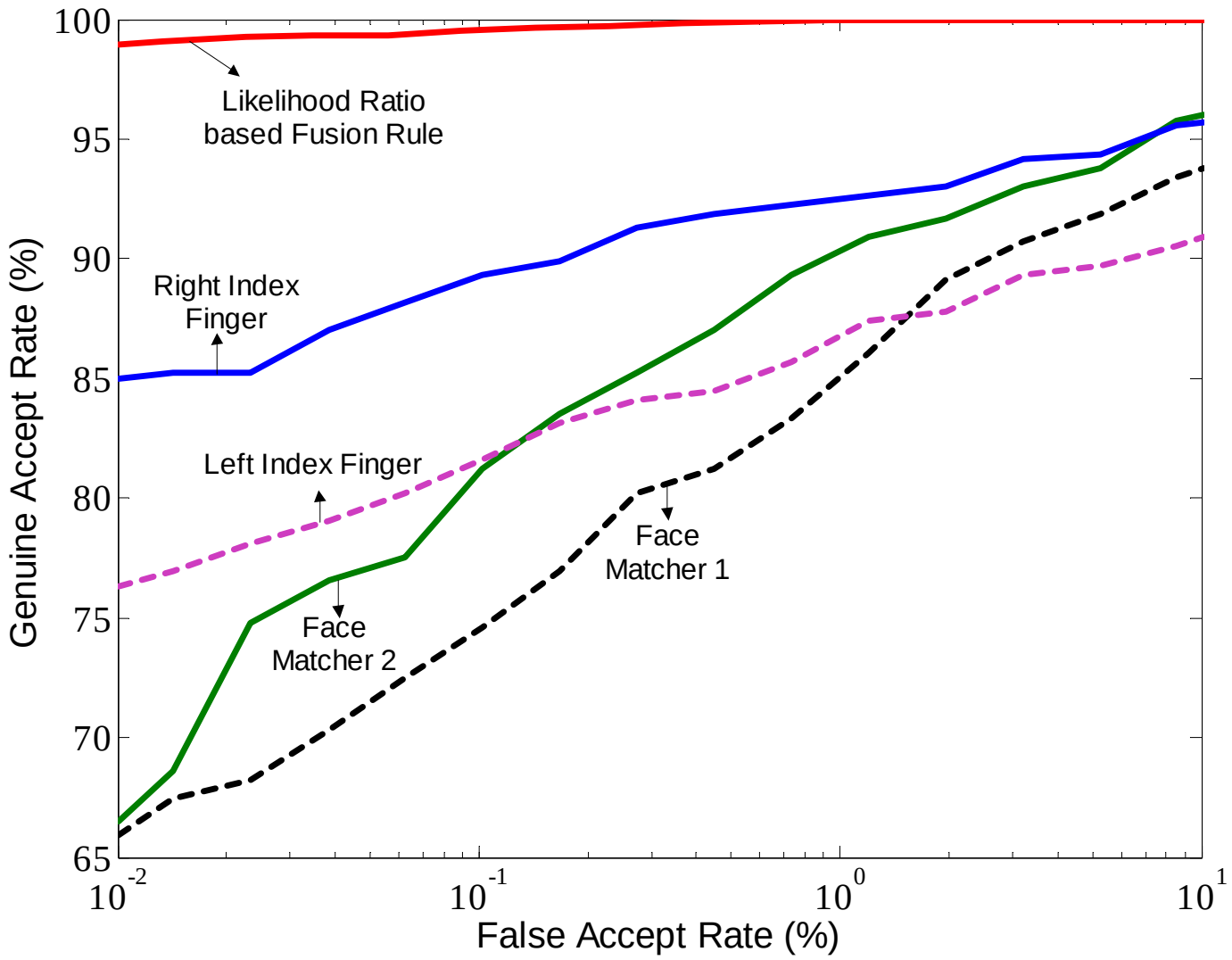
Courtesy TBS, NA

Whole Hand Sensor



Courtesy, Lumidigm

Fusion of Face and Fingerprints



K. Nandakumar, Y. Chen, S. Dass, A.K. Jain, IEEE Trans. PAMI, Feb 2008

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