Biometrics
Successes, Innovations and Challenges

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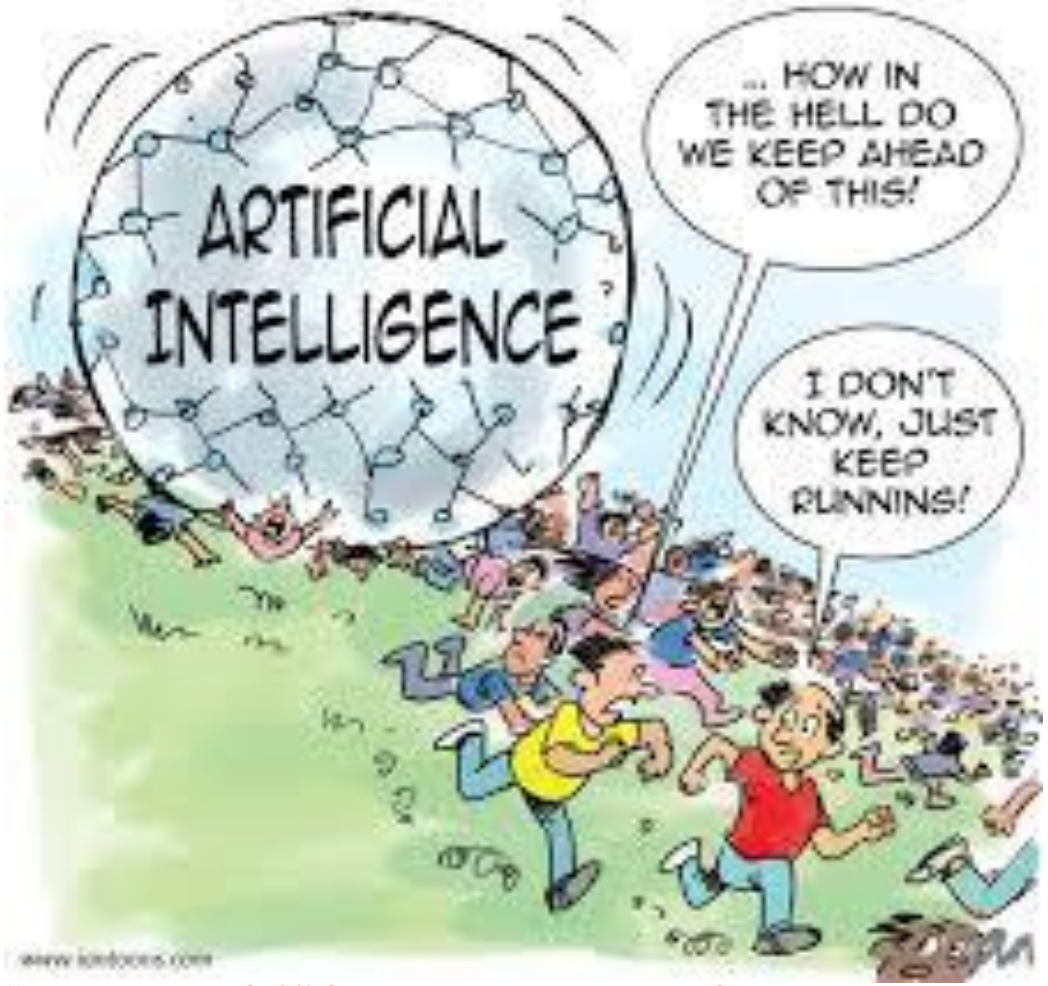
Computer Analysis of Images and Patterns (CAIP), Las Palmas, September 23, 2025

Images and pattern of human body

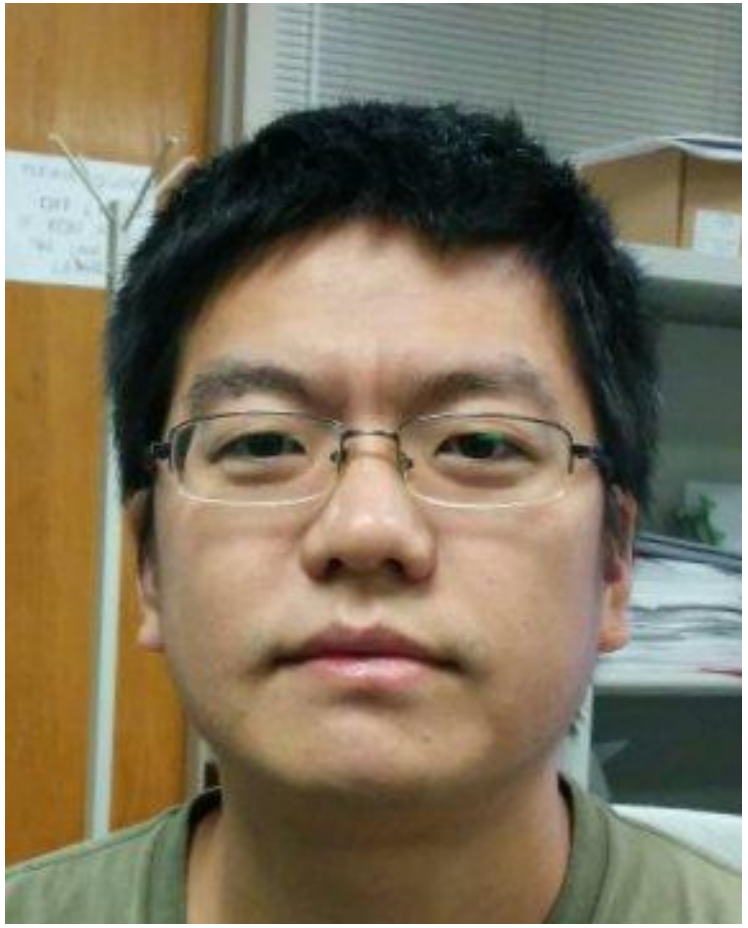
Artificial Intelligence

"AI AI, AI, AI. enjoy and don't cry; let Artificial Intelligence work for you." (Bilbao, June 2025).



"Are we ready?" by Iantoons. AI is advancing at pace, but we do not have all the unintended consequences worked out yet.

Authentication: Pairwise Similarity



Selfie (Kai Cao)

Similarity = 0.56

Scanned driver license

Challenge: Choose a robust and salient representation

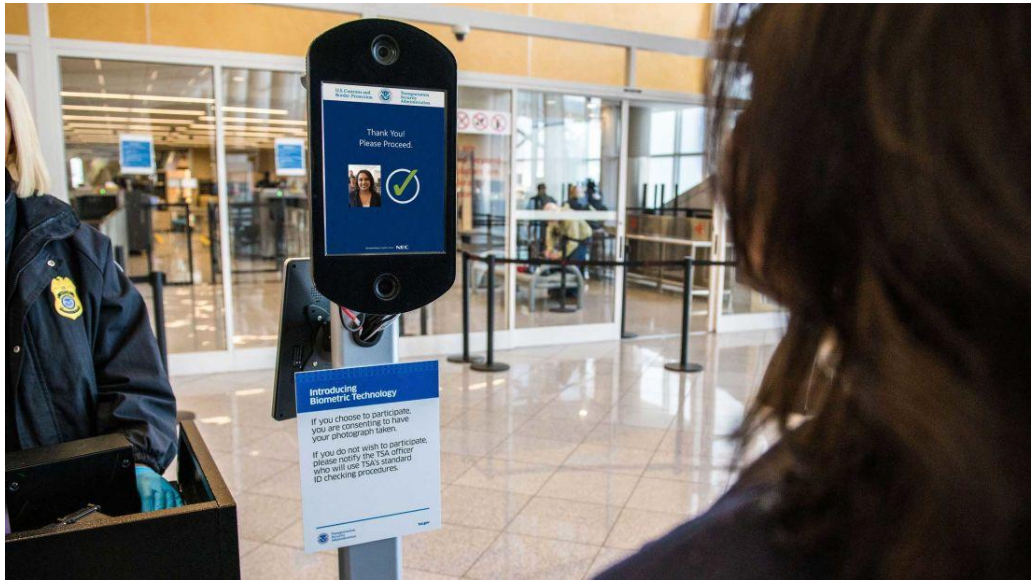
Identification: 1:N Comparisons

Probe *Gallery*

The probe may or may not be in the gallery

Face Recognition @ Airports (1:N)

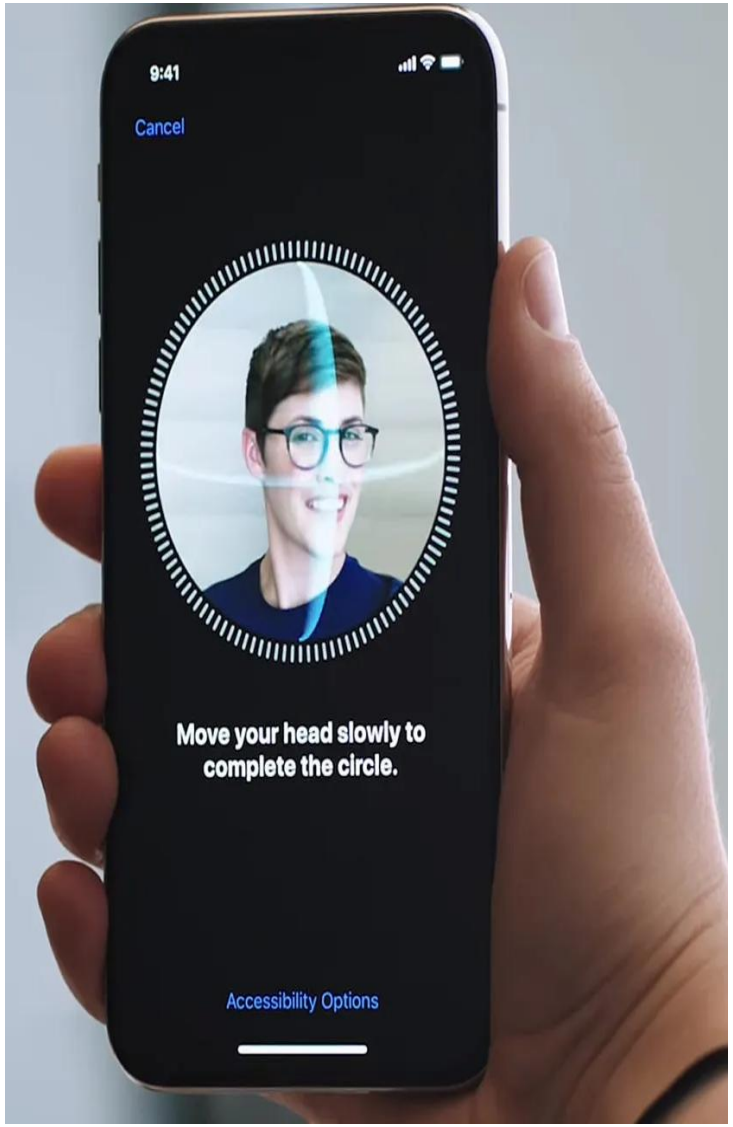
~66M travelers in 2024 at Madrid-Barajas Airport



How Airports Are Improving Travel

900,000 US passports were reported lost or stolen between January 2024--July 2025 (NY Times, Sept 7, 2025)

Face Recognition for Mobile Unlock (1:1)



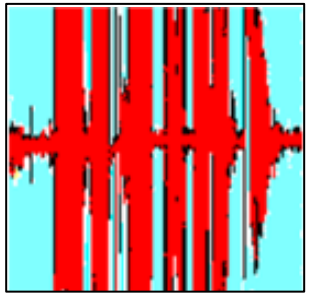
Face ID, iPhone X (2017); self enrollment

1.2 bn smartphones sold in 2024; 80% with biometrics

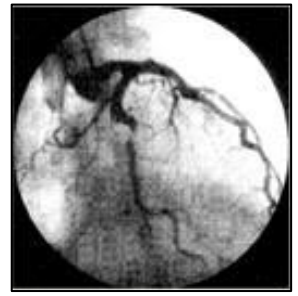
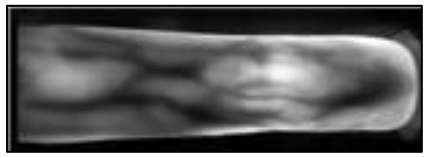
Biometric Recognition

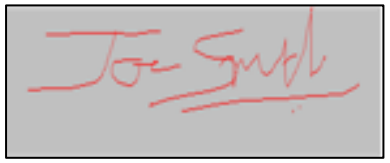
- We can no longer **trust** people based on PIN/PW & even government issued ID.
- Biometric Recognition: Automated, real-time person recognition by **body trait(s).**
- **Biometrics is the only way to assure "*a person is who they say they are.*"**

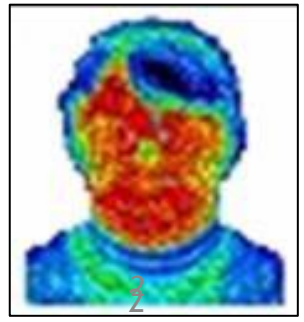


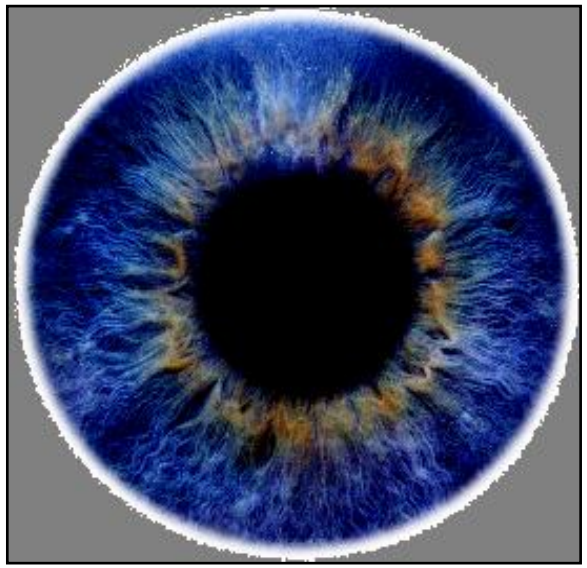


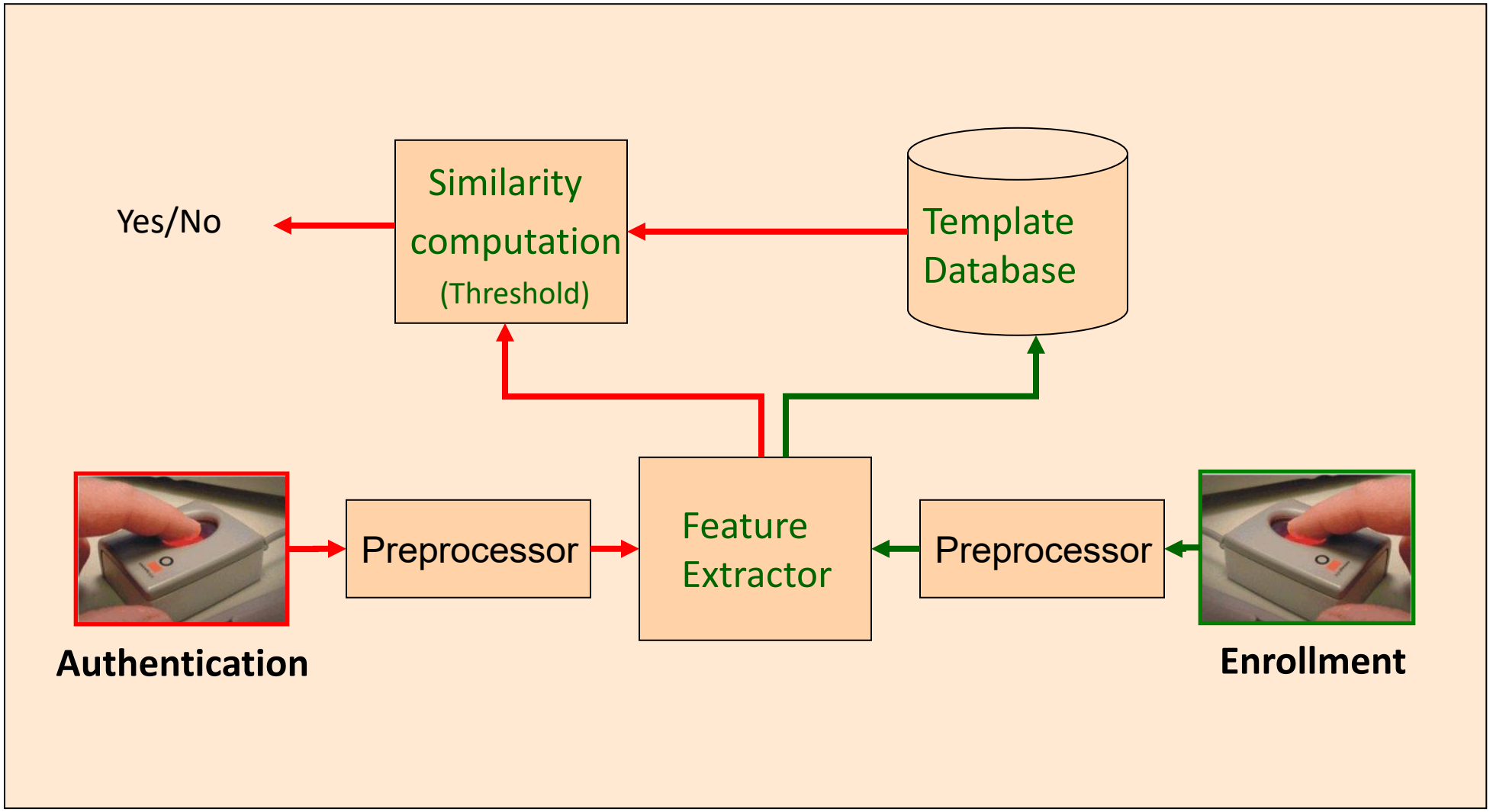



Most Frequently Used Body Traits



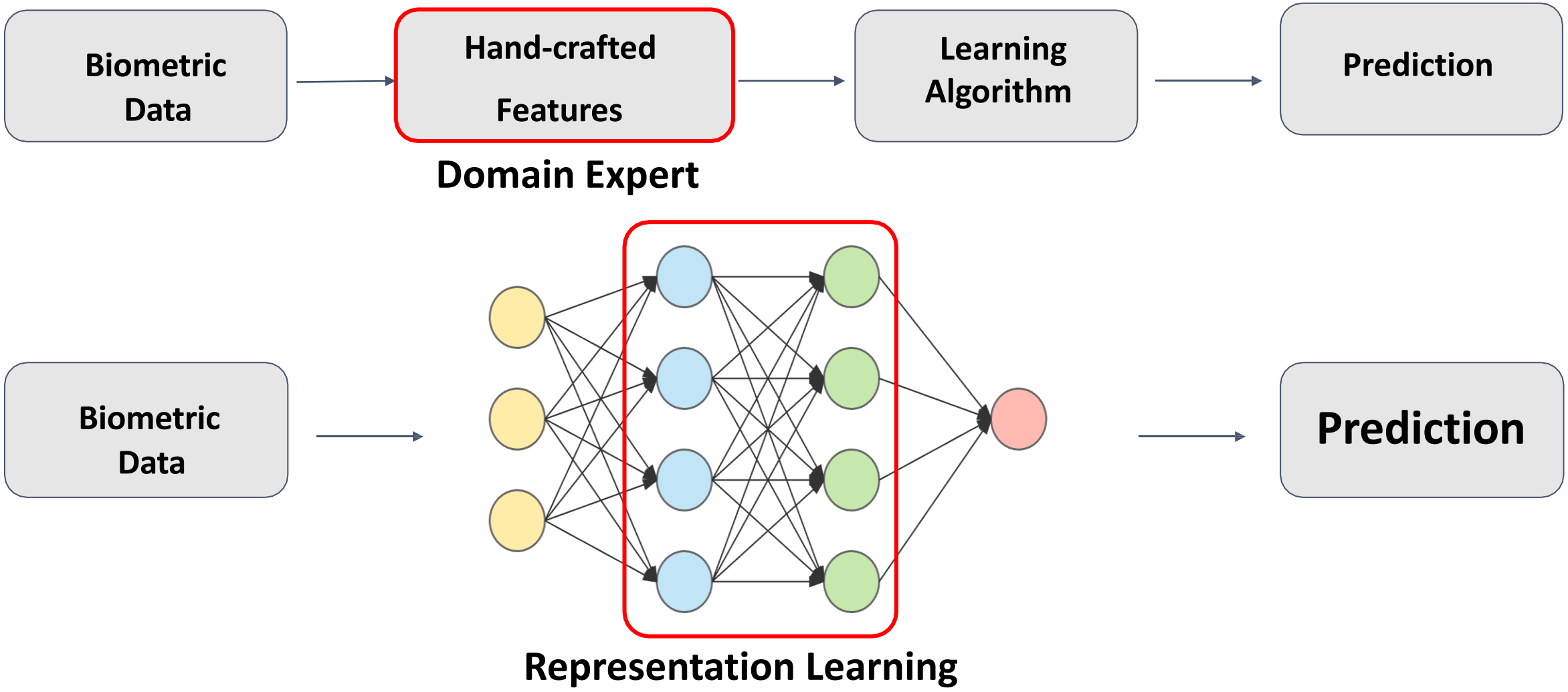
- Satisfy (?) **Individuality** and **permanence** properties; legacy databases.
- World population: 8.2B; **82 billion "distinct"** fingerprints!!
- Low face error rate in NIST: FNIR=0.0190 @ FPIR = 0.001; N=12M subjects.
- Extremely low latency: **~50 million face comparisons/second**.

Biometric Recognition Systems



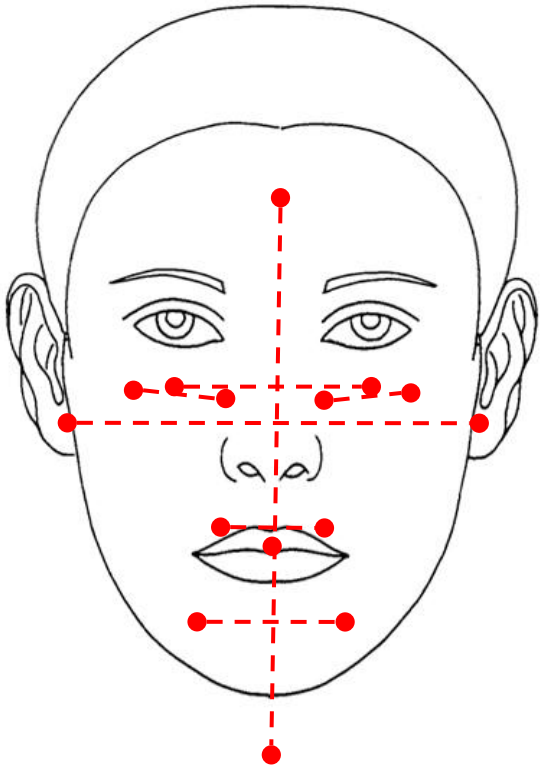
Template: compact & salient representation of biometric image/signal

How to Compute Pair-wise Similarity?



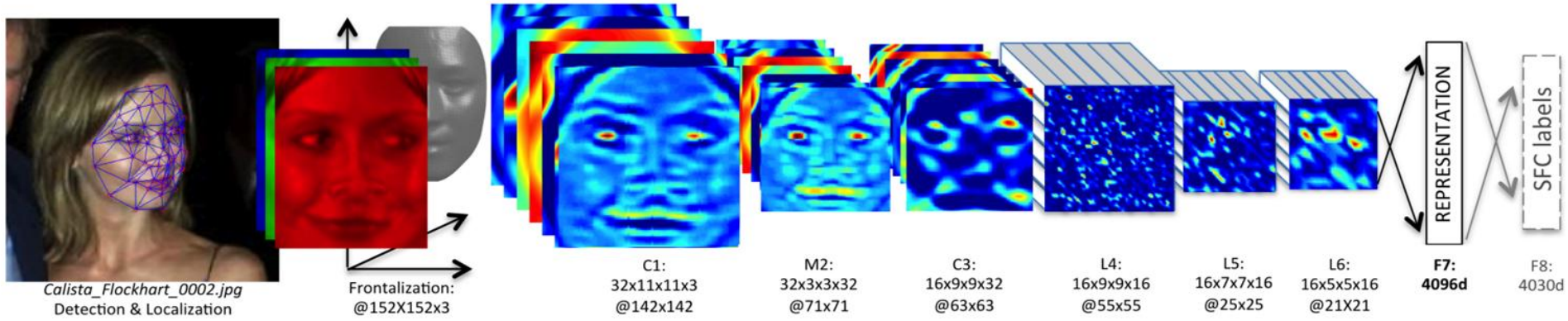
Why not utilize both the representations?

Faces: Landmarks to Embeddings



20 inter-point distances for matching
Bledsoe (1966)

Deep networks enabled progress in face recognition; but they lack interpretability of features and cannot explain why two faces belong to the same person.

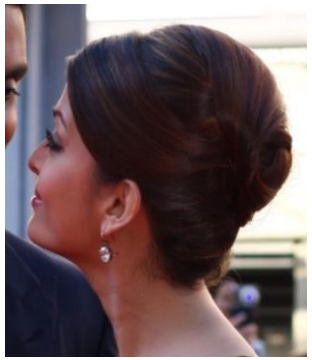


Taigman, Yang, Ranzato, and Wolf. "Deepface: Closing the gap to human-level performance in face verification." CVPR, 2014
https://www.historyofinformation.com/detail.php?entryid=2495

Intra-person Variations and Inter-Person Similarity

Probe

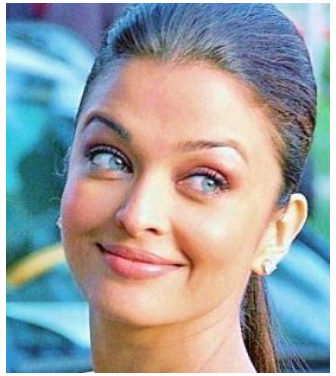
0.991



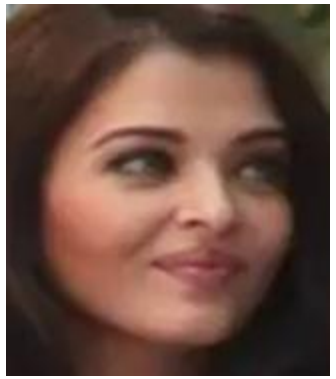
0.743

0.241 (doppelganger

0.991



0.991

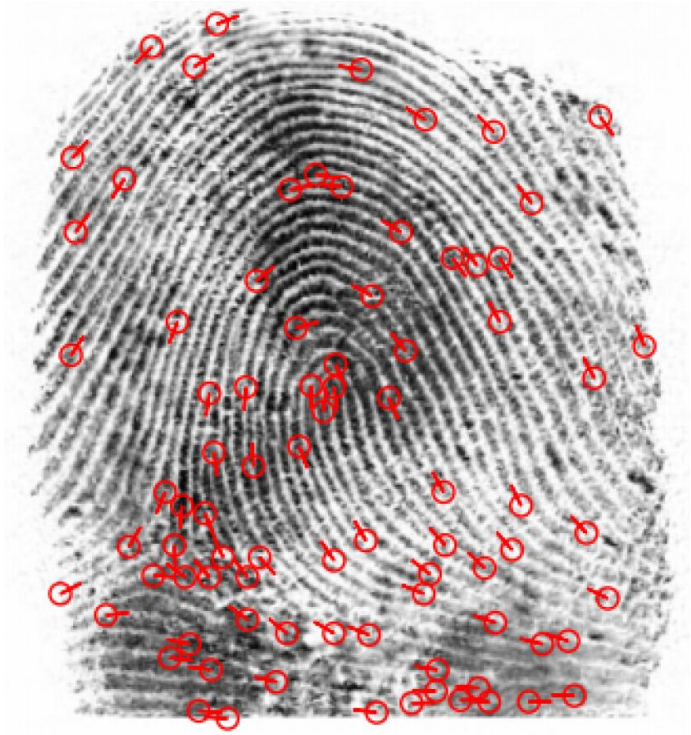


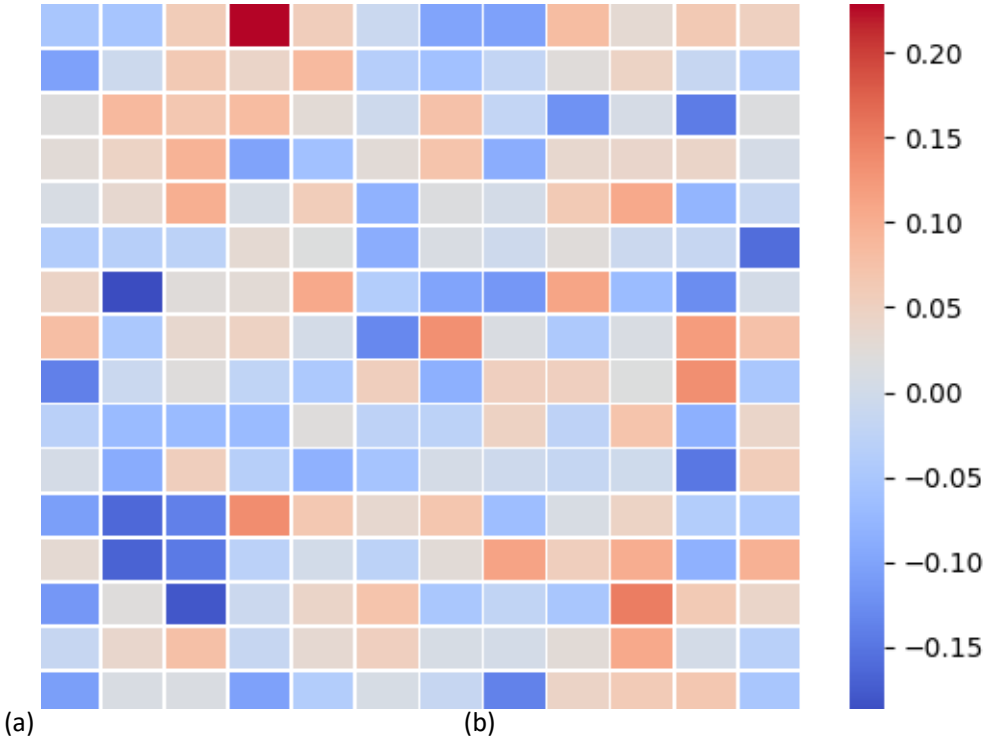
0.995

0.991 (identical twins)

Identical twins occur in approximately 3.5 out of every 1,000 births

Fingerprints: Minutiae to Embeddings



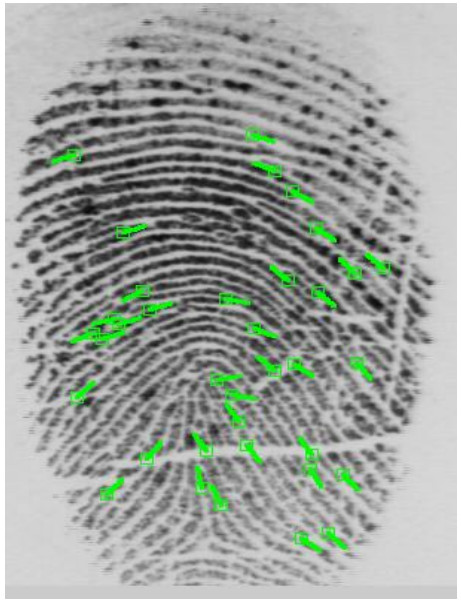


- Minutiae points & 192-dimensional embedding shown as 16 x 12 heat map.
- Fusion of these two representations improves recognition accuracy.

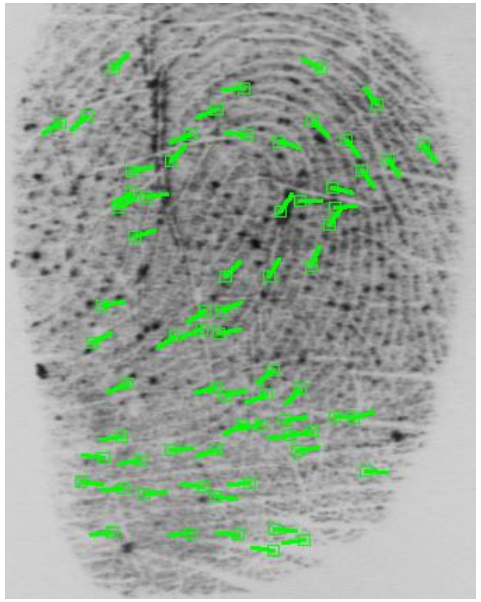
Engelsma, Cao and Jain, "Learning a Fixed-Length Fingerprint Representation", IEEE Trans. on Pattern Analysis and Machine Intelligence, 2019

Invariance to Fingerprint Quality

No. of false minutiae = 0



No. of false minutiae = 7



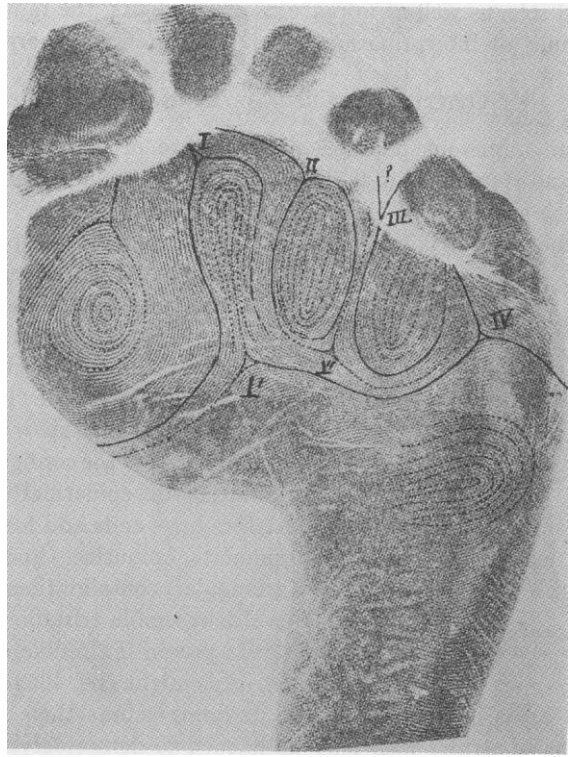
No. of false minutiae = 27

Beginnings of Biometric Recognition

Habitual Criminal Act (1869)

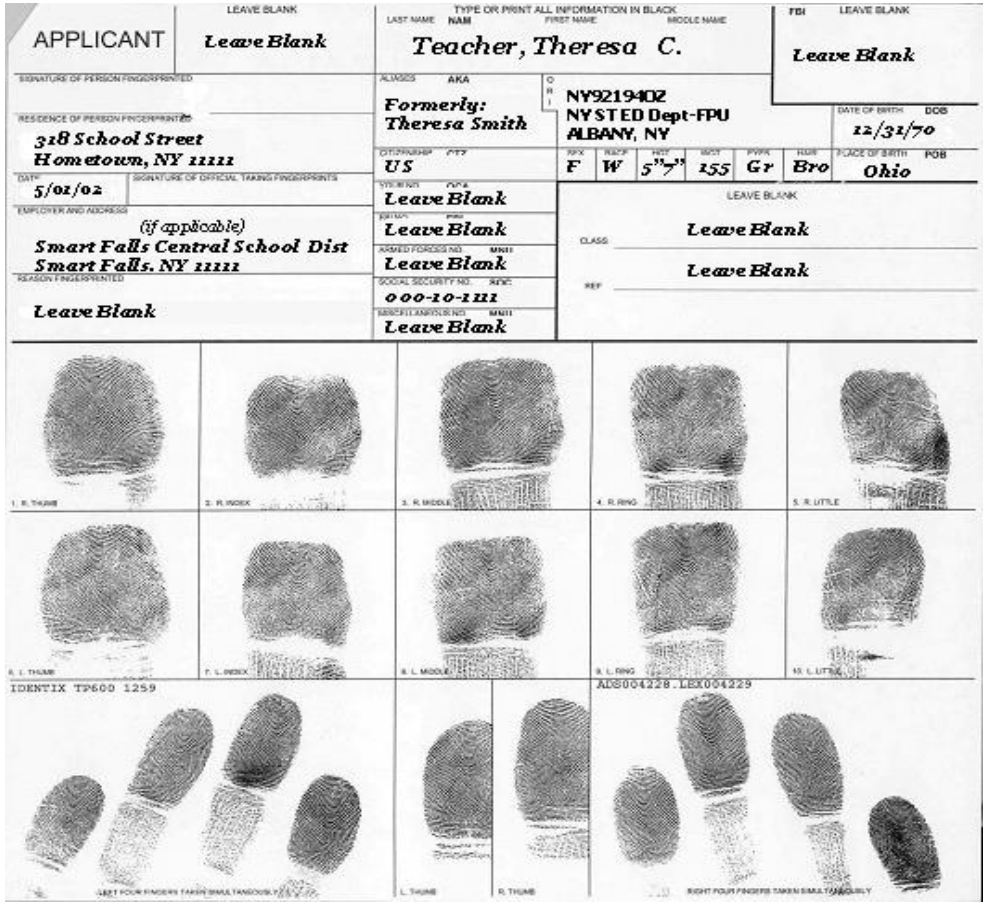
"What is wanted is a means of classifying the records of habitual criminals, such that as soon as the particulars of the personality of any prisoner (whether description, measurements, marks, or photographs) are received, it may be possible to ascertain readily, and with certainty, whether his case is in the register, and if so, who he is."

Friction Ridge Patterns (~ 1880)



https://digitalcommons.osgoode.yorku.ca/cgi/viewcontent.cgi?article=1968&context=ohlj

Success Story #1: FBI Adopts Fingerprints (1924)


APPLICANT

Leave Blank

Teacher, Theresa C.

Leave Blank

Formerly: Theresa Smith

NY9219402
NYSTED Dept-FPU
ALBANY, NY

318 School Street
Hometown, NY 11111

12/31/70

US

F W 5"7" 155 Gr Bro

Ohio

5/01/02

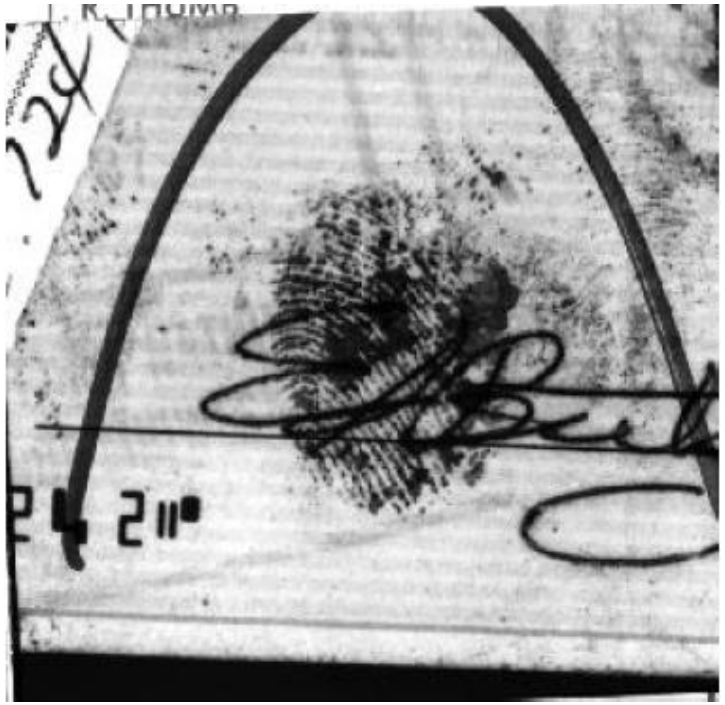
(if applicable)
Smart Falls Central School Dist
Smart Falls, NY 11111

Leave Blank

000-10-1111

IDENTIX TP600 1259

FBI Tenprint (TP) card, 1924

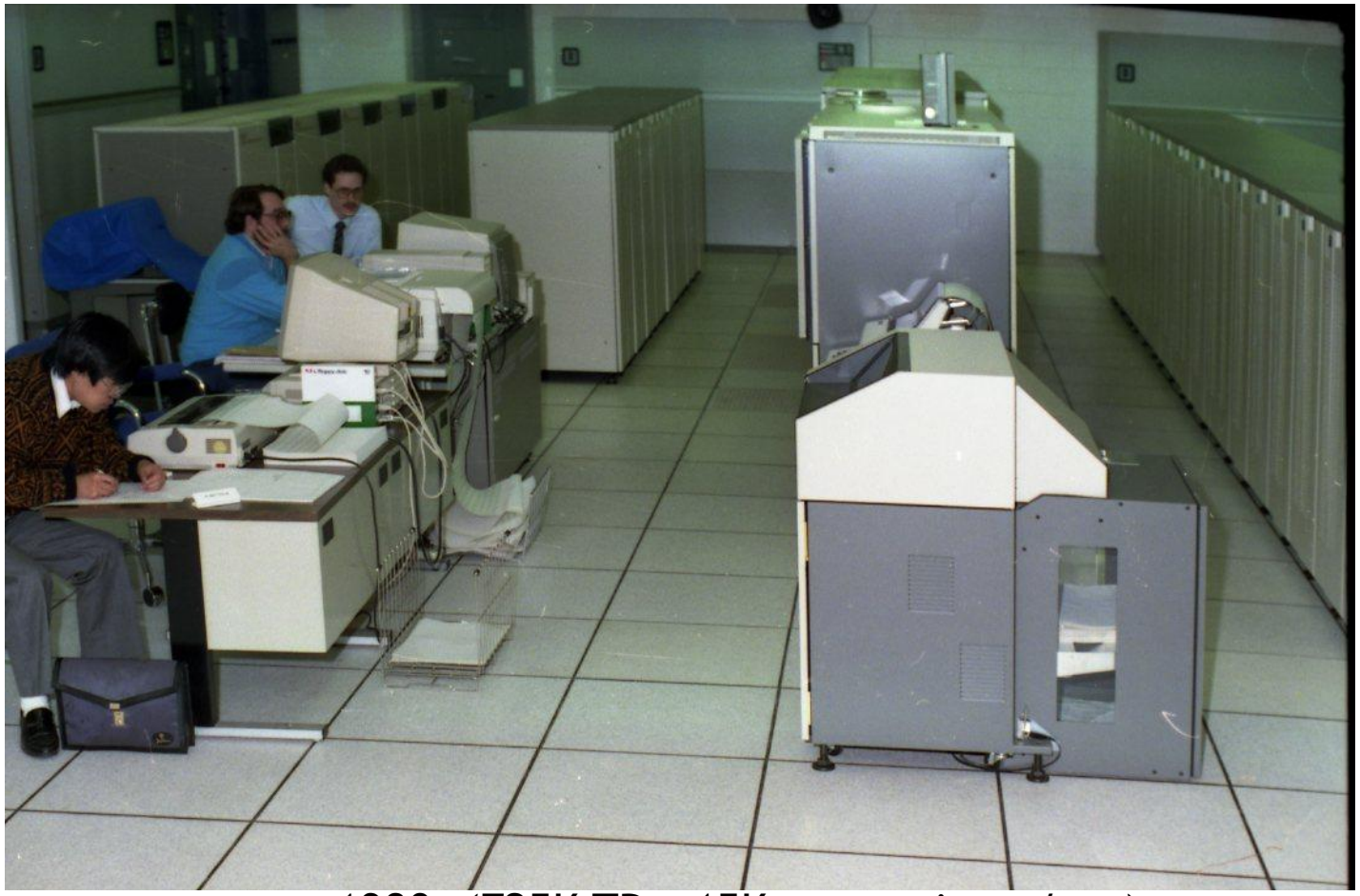


Latent print from a crime scene (LP)

- TP to TP search: Background check for prior criminal history; individual finger scores fused.
- LP to TP search: who left partial print at crime scene? Difficult problem.

From Manual Comparison to AFIS

1960

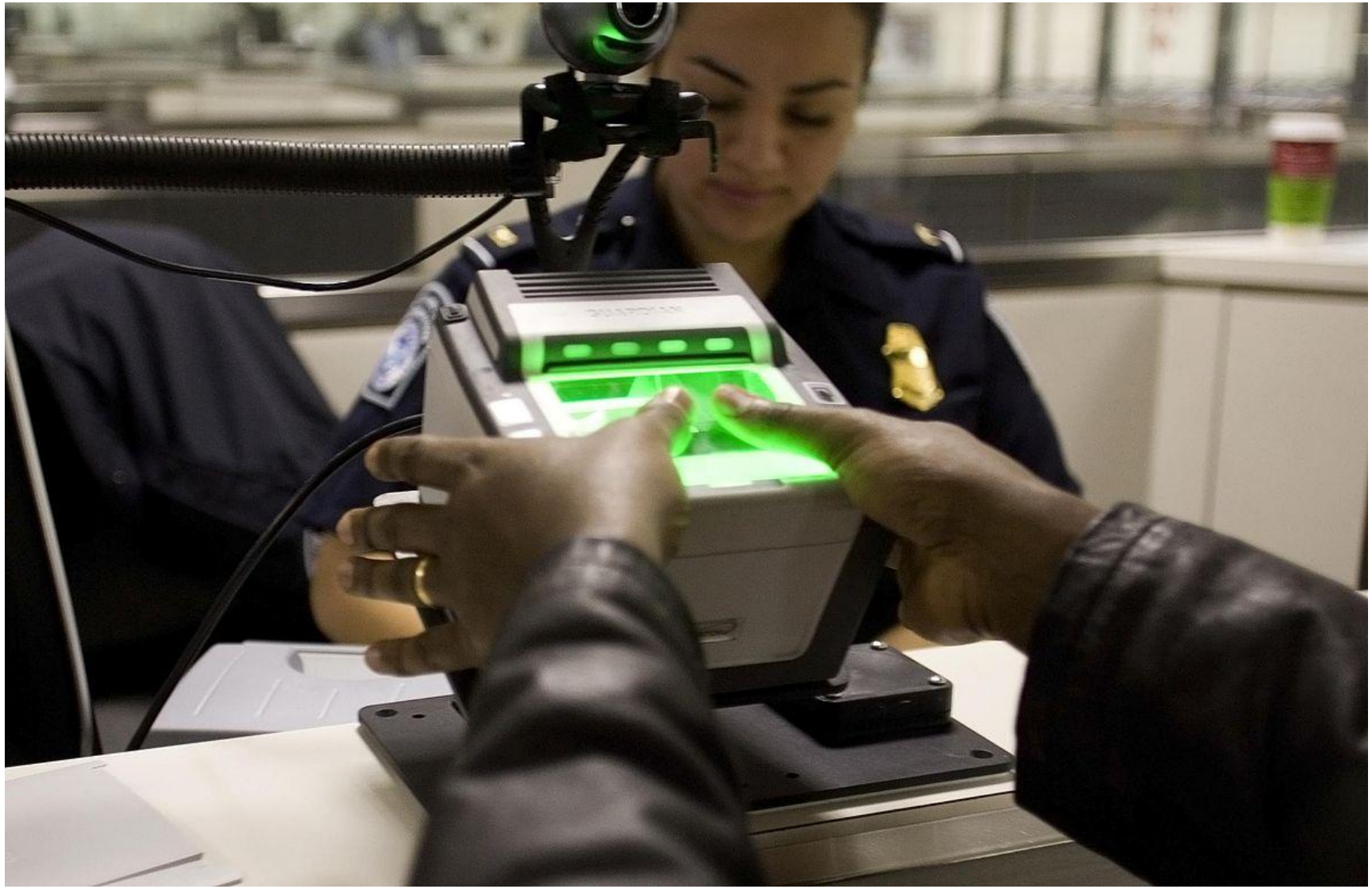


1980s (725K TPs; 15K comparisons/sec)

- **FBI Face & fingerprint repository (July 2025): ~170M master tenprints, access to 640M photos**
- **Average daily requests for search: ~200K (30K criminal; 120K civil; 50K other)**

9/11 Terrorist Attacks (2001)

Success Story #2: US-VISIT(2003)

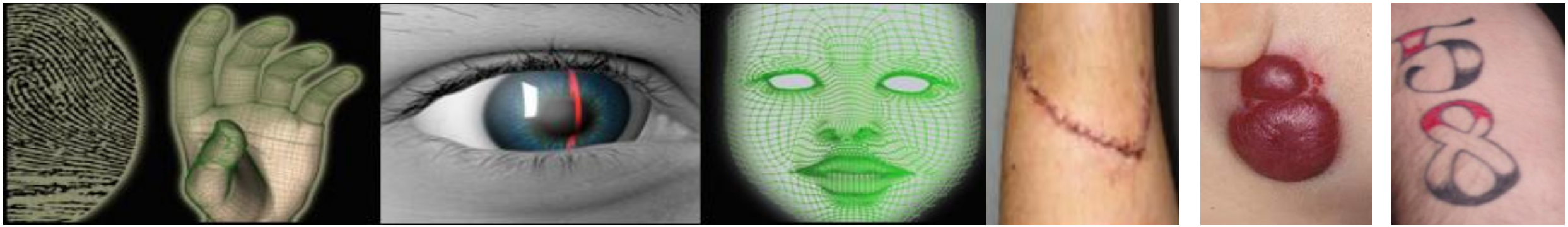


USA Patriot Act: enhance national security by using biometrics for tracking terrorists (2001)

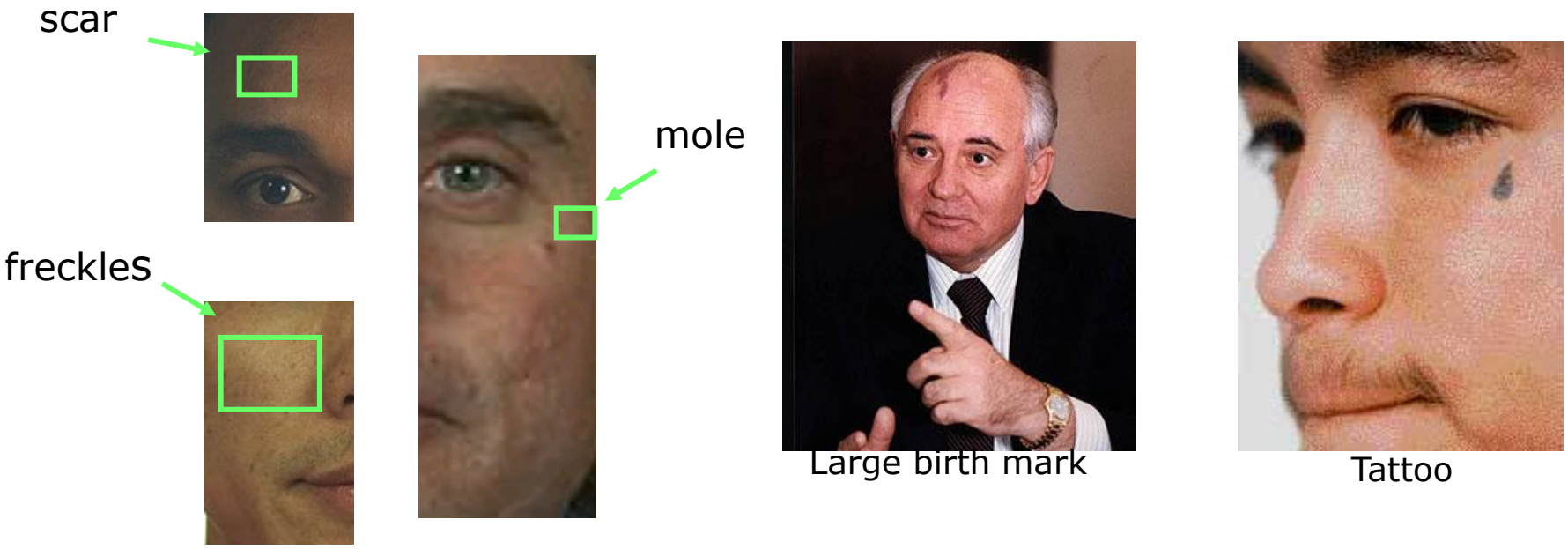
Entry/Exit Systems (ongoing)

- Airport entrance, baggage drop-off & flight boarding use face recognition.
- Passenger photo is compared with DHS database (passports, flight manifest).

FBI Next Generation Identification (2008)



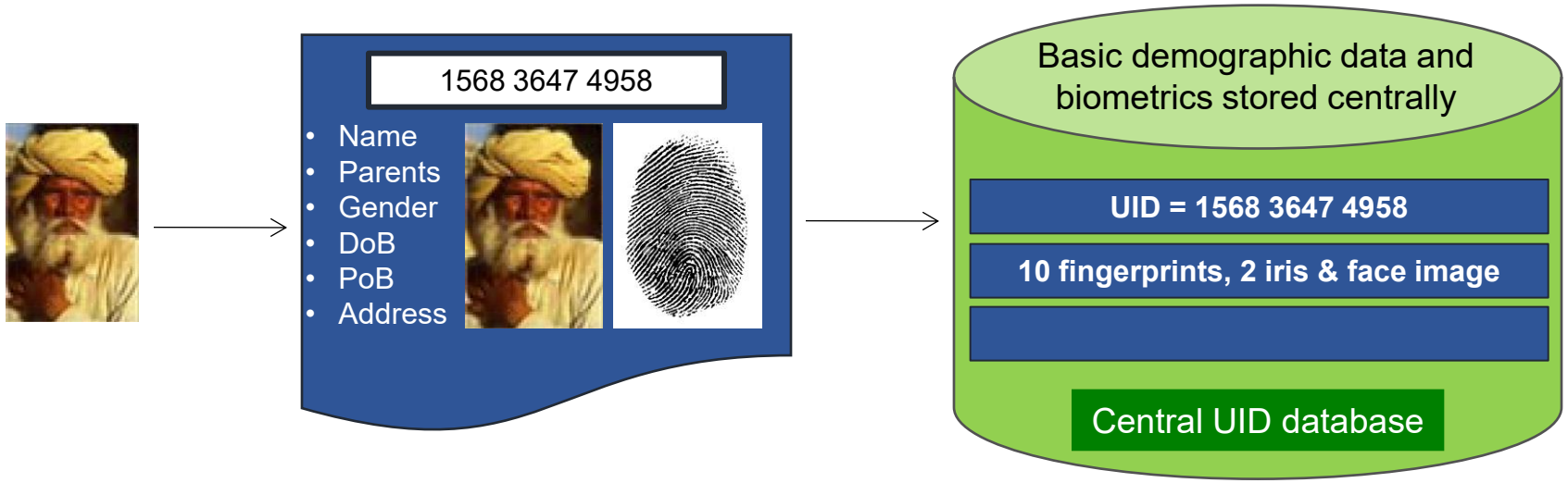
First AFIS in1980s; IAFIS launched in 1999; use of palmprint, iris, scars, marks & tattoos (2008)



http://www.fbi.gov/about-us/cjis/fingerprints_biometrics/ngi/ngi2/

Success Story #3: Aadhaar (2008)

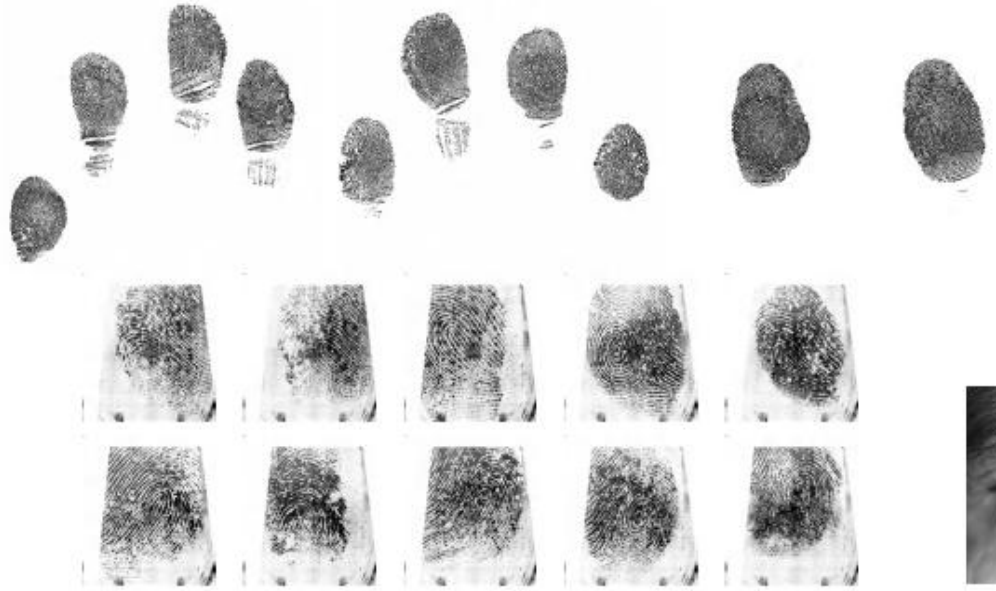
Issue a 12-digit unique identification number (UID) to Indian residents that can be used to eliminate duplicate and fake identities.



Efficient, transparent, and targeted delivery of subsidies verified by biometrics

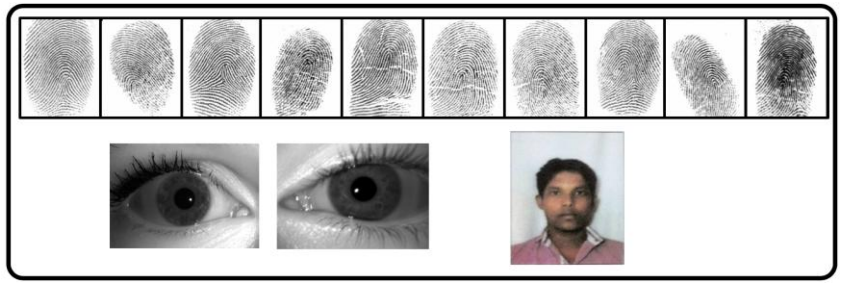
https://uidai.gov.in/

Enrollment

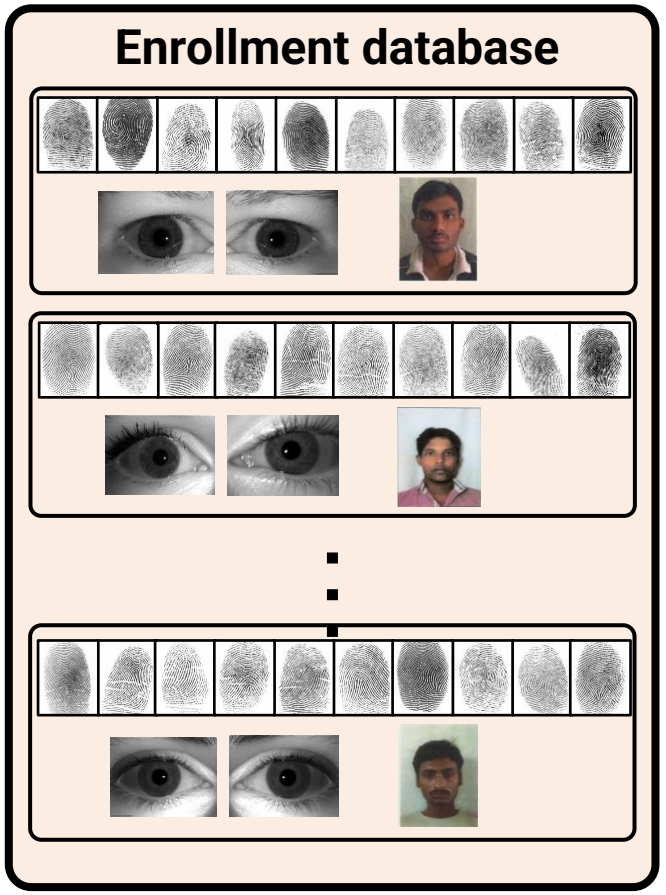


Face, slap fingerprints (4-4-2) and 2 iris images are captured; ~1.4 billion enrollment.

De-duplication (1 to 1.4 billion comparison)



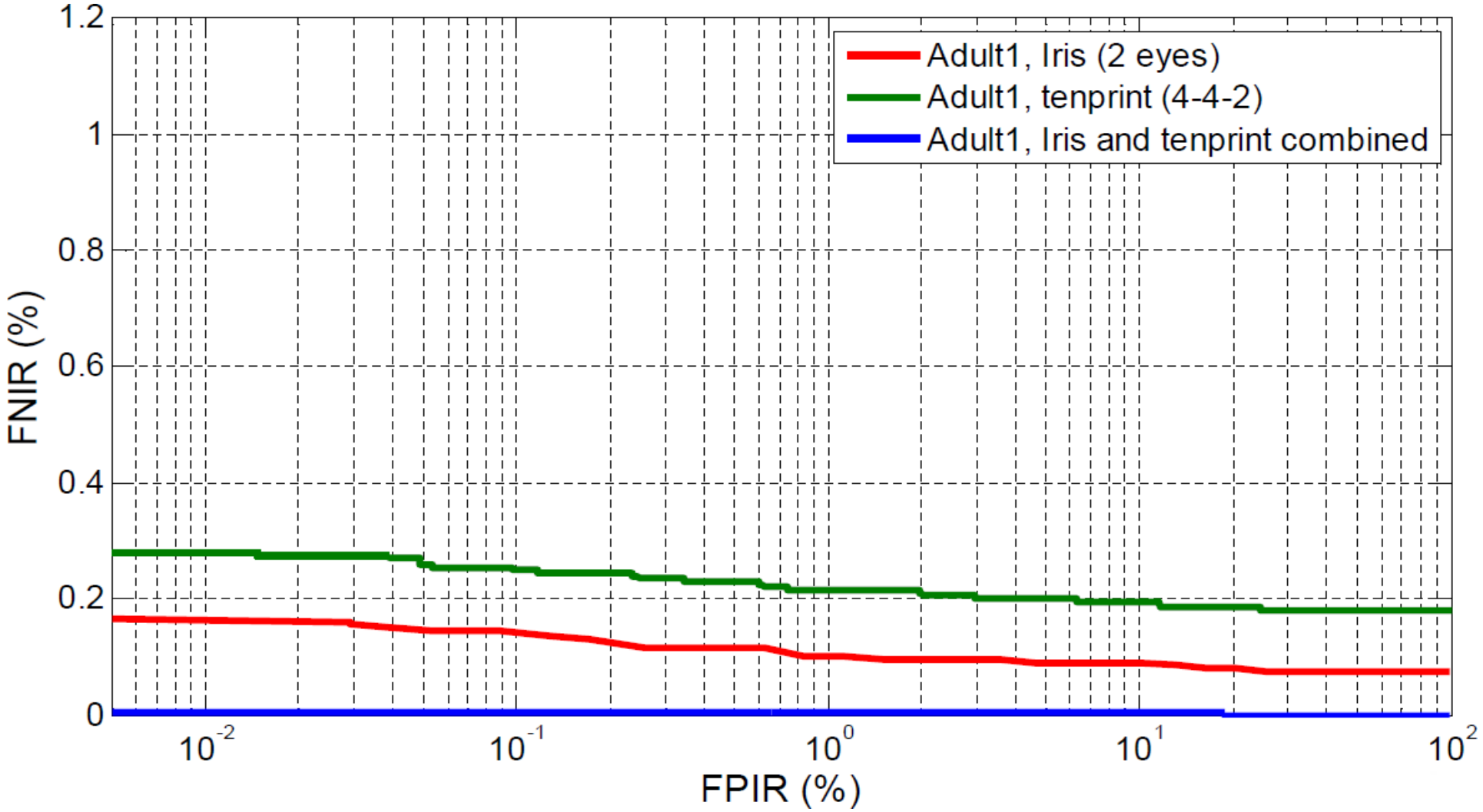
Biometrics of new Applicant
(No demographic info is used)



Already in Database?

Fusion of 10 fingerprints, two irises and face is necessary to distinguish among ~1.4 billion individuals

Benefit of Biometric Fusion



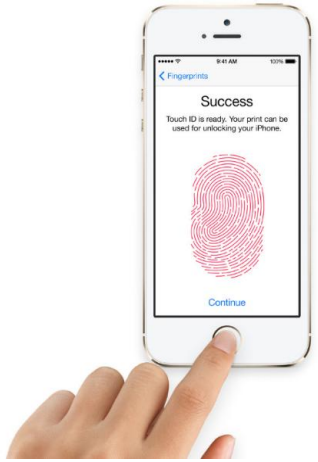
- **FPIR: Fraction of non-mated searches where one or more enrolled identities are returned at or above the threshold**
- **FNIR: Fraction of mated searches where the enrolled mate is outside the top R rank or comparison score is below the threshold**

Authentication (12-digit ID + fingerprint)

~80 million biometric-enabled authentications/day

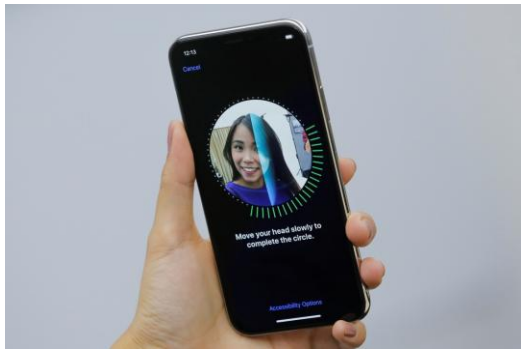
Success Story #4: Mobile Phone Unlock & Payment

The Pantech GI100 (2004)



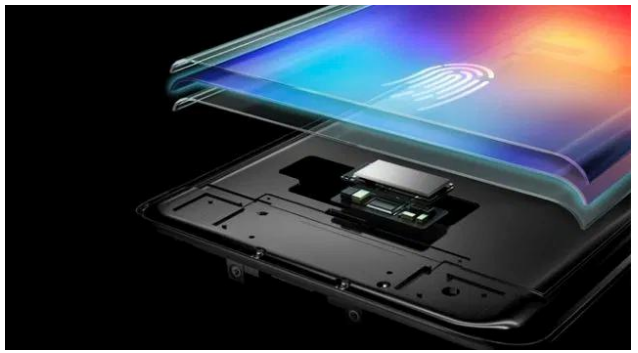
Touch ID, iPhone 5S (2013)

Apple Pay, iPhone 6 (2014)



Face ID, iPhone X (2017)

Delta ID, phone with iris



Vivo In-Display Scanner (2018)

Galaxy S10's in-screen ultrasonic

Touch ID was revolutionary: convenience, accuracy, security, cost (1$ US) & latency

https://www.theverge.com/23868464/apple-iphone-touch-id-fingerprint-security-ten-year-anniversary

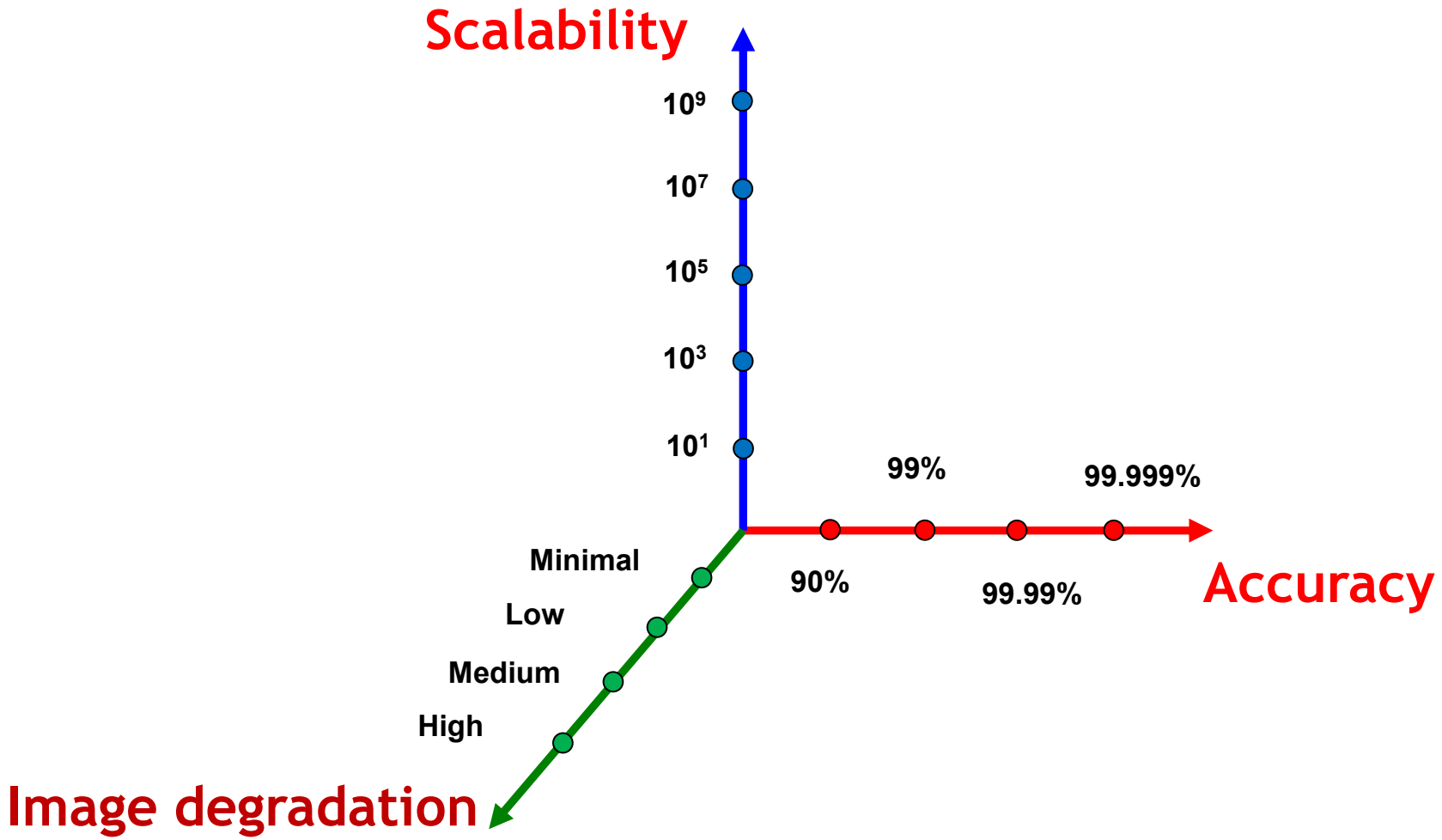
Biometric Recognition Accuracy: NIST

1. **Face (constrained to semi-constrained)**
   - 1:1 comparison: FNMR = 0.0026 @ FMR = 0.000001. One in a million chance *you may be mistaken as someone else* and 26 out of 10,000 times you may not be recognized as you.
   - 1:N comparison (N=12M): FNIR=0.0190 @ FPIR = 0.001.
2. **Fingerprint**

- One-finger (five-finger) Accuracy: FNMR=0.0047 (0.0011) @ FMR=0.0001. One in 10,000 chance of you being mistaken as someone else, and 47 out of 10,000 times you may not be recognized as you.
- Latent fingerprint accuracy (N=32M) Rank-1 retrieval=96.12%.

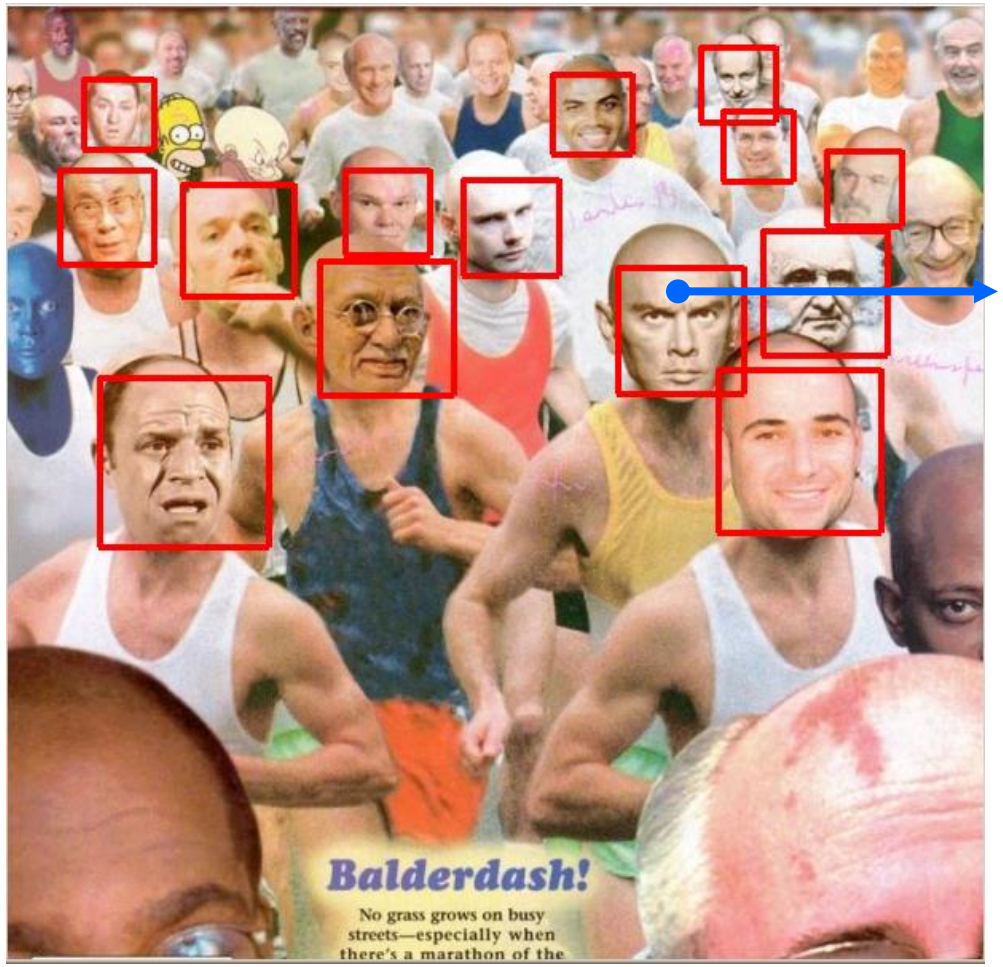
https://pages.nist.gov/frvt/reports/1N/frvt_1N_report.pdf

Challenges and Opportunities



Throughput, presentation attacks, template security, usability, acceptability

Face Detection



Segmentation of individual faces

?

Gallery

1959

1960

1972

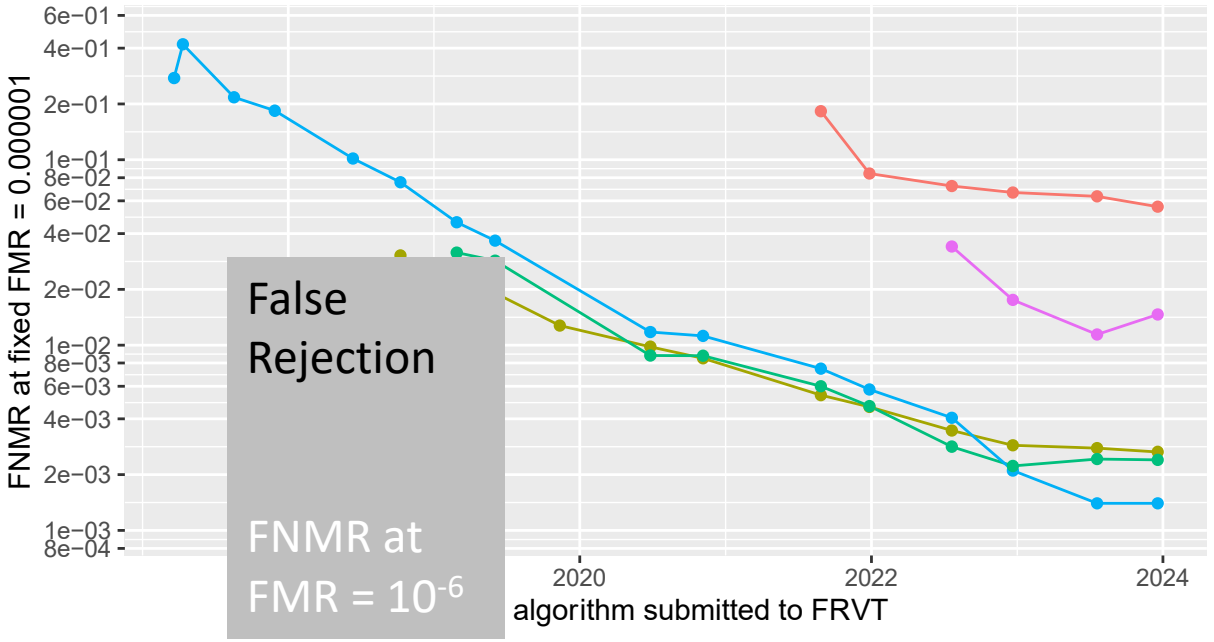
1973

Yul Brenner (1920-1985); The King and I (1956), Ten Commandments (1956),..

1:1 Face Accuracy Gains Continue

Conclusion:
- Algorithms improve regularly
- Accuracy depends on test data

28%



False Rejection

FNMR at FMR = 10^{-6}

< 0.2%

Date Algorithm Delivered to NIST

Challenges: Large pose change, image quality, aging

False Non-Match

Similarity = **0.20**

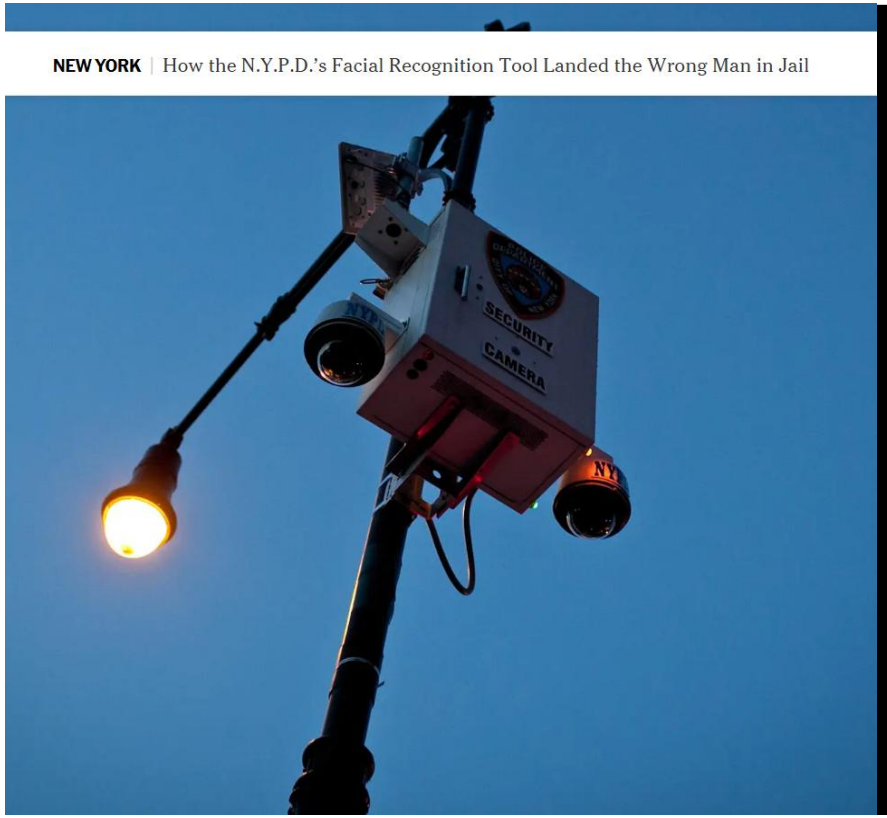
Similarity = **0.19**

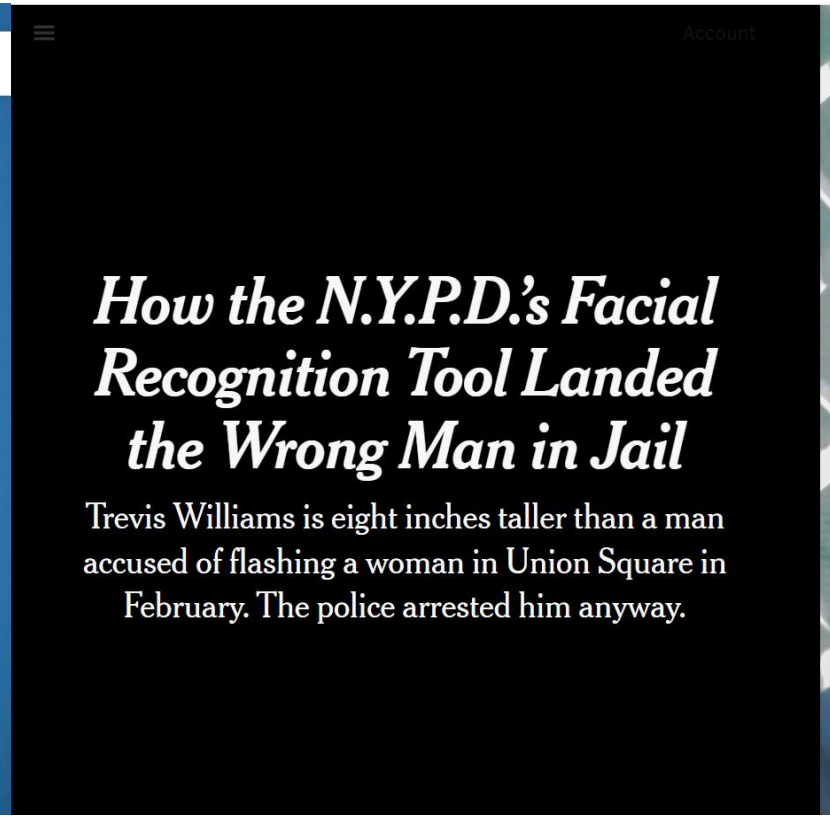
False Match

Similarity **0.64**

Similarity **0.61**

Wrongful Arrest Based on Face Recognition Technology

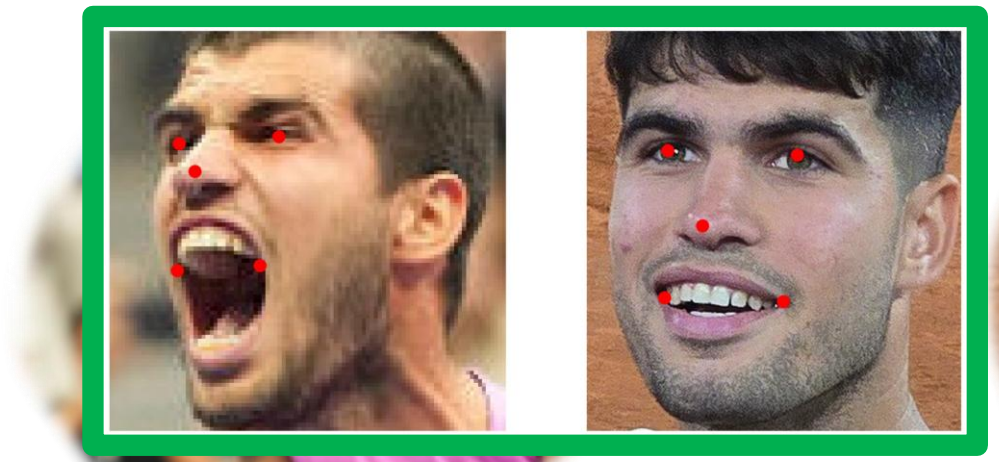




- **SOTA algorithms have 99.9% search accuracy, but it drops significantly for low-quality CCTV frames images are used, as in CCTV frames.**
- **It is not always the fault of technology, but how it is used.**

How the N.Y.P.D.'s Facial Recognition Tool Landed the Wrong Man in Jail - The New York Times

Unconstrained Face Recognition



Match Score (KPE-RPE [1]): **0.5085**

Tight Crop

Sep 7, 2025

Match Score (KP-RPE[1]): **0.4296**

Loose Crop

June 28, 2015

Minchul Kim, Yiyang Su, Feng Liu, Anil Jain and Xiaoming Liu "Keypoint relative position encoding for face recognition." *CVPR*. 2024

Vision Language Models to Generate Explanations

Date: Sep 7, 2025

Date: June 28, 2015

GPT-4o Prompt: Please examine these two face images. Are they of the same person or not? Explain your reasoning.

- **Jawline & Chin**: Both individuals have a broad, angular jawline with a prominent chin.
- **Eyebrows & Forehead**: Dense, straight eyebrows and similar brow ridge shape.
- **Nose Shape**: The nose bridge and nostril shape are consistent across both images.
- **Smile & Teeth**: Identical teeth shape and smile structure in the second image matches the expressive shout in the first.
- **Skin Tone & Texture**

Identical skin tone and minor facial blemishes (such as faint moles or acne spots) align well between the two images.

- **Hairline & Hair Texture**

While the hairstyle is slightly different, the hair texture, direction of hair growth, and hairline shape are consistent.

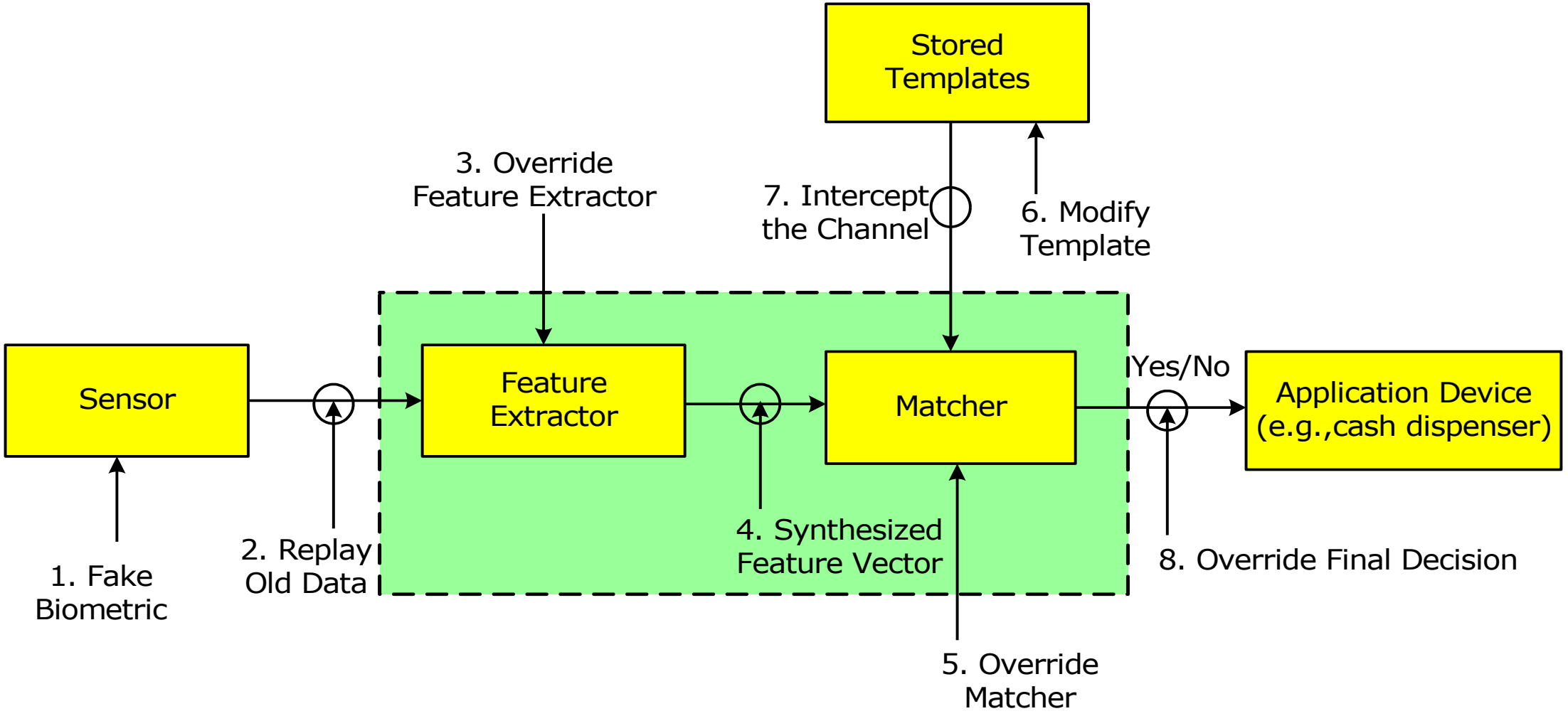
- **Clothing & Context Clues**

Both are wearing **Nike-branded sports gear**, suggesting they are in similar athletic contexts — consistent with a professional tennis player.

"Therefore, yes, the two images are of the same person. The facial features, expressions, context, and fine details all strongly align. The similarity score is 94.7"

Sony, Redwan, Parisa Fradaminaz, Arun Ross and Anil Jain, "Foundation versus domain-specific models: Performance comparison, fusion, and explainability in face recognition", ICCVW (2025).

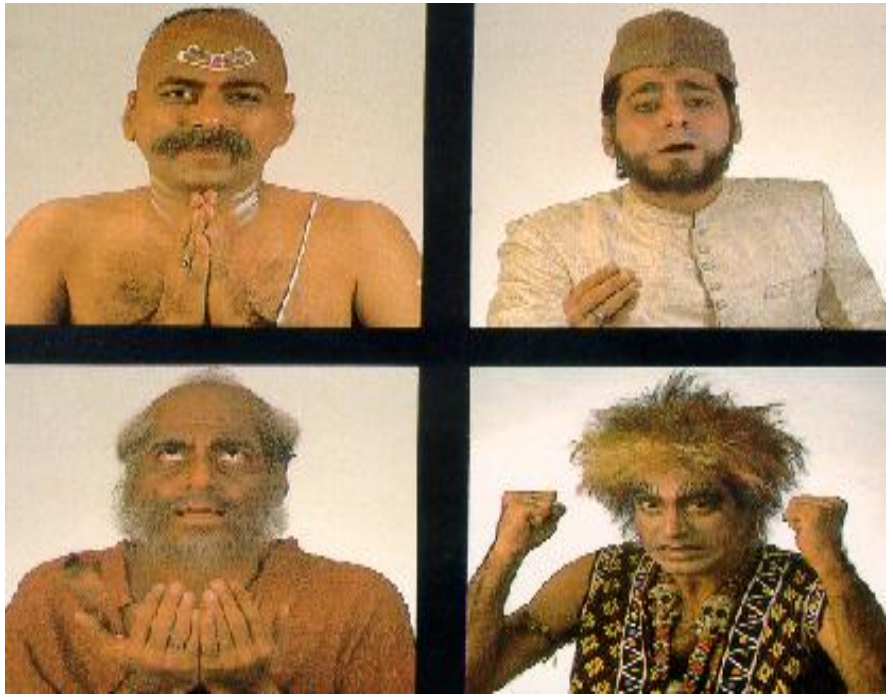
Security of Biometric Systems



Ratha, Connell, Bolle, "Enhancing security and privacy in biometrics-based authentication systems", IBM Systems Journal, 2001

Presentation Attacks

Gummy finger



Face disguise

Silicone Mask

Print

Fake hand

Fake eyeball

Fingerprint alteration

Iarpa Odin benchmark: **TDR = 98% @FAR =0.2%**

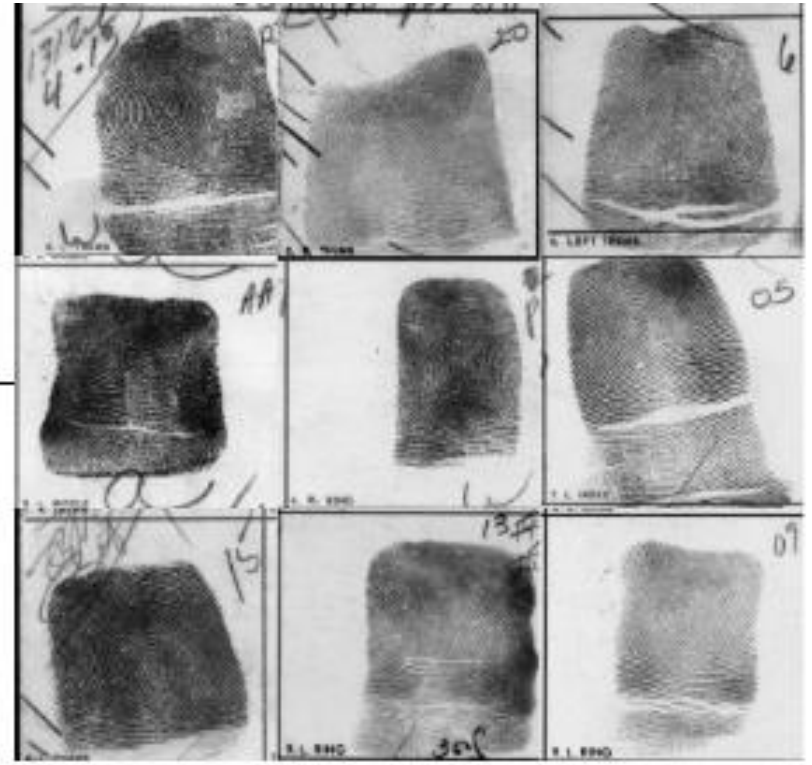
Privacy-Preserving Authentication

Fingerprint Reader

Encrypted Query

Matching in encrypted domain

Encrypted Scores



Enrolled database

Accurate & fast image search in encrypted domain is feasible @100 M gallery; no leakage of biometric

Engelsma, Jain and Boddeti, "HERS: Homomorphically Encrypted Representation Search", IEEE T-BIOM, 2021.

Summary

- **Biometrics is the only way to assure "*a person is who they say they are.*"**
- Fingerprint and face will continue to dominate the market; use of face is growing (e.g., ID verification, surveillance).
- Growing deployments: national-level civil registration, border crossing, banking, PoS payment, travel and immigration.
- Research challenges: recognition under non-ideal conditions, access to large data (real + synthetic), use NIST benchmarks to understand SOTA (accuracy + latency), multi-model & muli-modal, presentation and deep fake attacks, RoI,..