

# Biometric Recognition

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# Outline

- What is biometrics?
- Why do we need biometrics?
- How did biometrics get started?
- Biometric milestones
- How do biometric systems work?
- What's Next?

# What is Biometrics?



**Palm-print payment devices for Tencent's WeChat Pay system**

<https://www.technologyreview.com/2022/11/15/1063218/whats-next-biometrics-palm-print-recognition-tencent-we-chat-pay/>

# What is Biometrics?

- Morris (1875): Derived from two Greek words  
*Bios: life; Metron: a measure*  
*Biometrika journal (1901-)*
- Pollack (1981): What makes each person unique?  
*Use of biometrics for access control*
- ISO/IEC JTC1 2382-37:2012  
*Automated recognition of individuals based on their behavioral and biological characteristics*

Stigler, "The Problematic Unity of Biometrics", BIOMETRIC5, S6 , Sept. 2000

Pollack, "Technology: Recognizing the Real You", NYT, Sep. 24, 1981

# Biometric Traits



- Multi-factor authentication
- Hard vs. soft biometric traits
- Multi-modal fusion

# Which Biometric Trait?

- Recognition accuracy
- Uniqueness and persistence
- Enrollment & recognition times
- User acceptance
- Resistance to spoofing
- Ease of integration

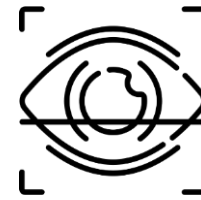
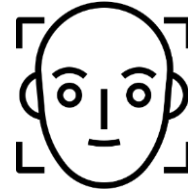
**Some traits are more useful than the others**



# Rejected Traits



# Most Popular Biometric Traits



Incheon, South Korea: Smart Entry



Australia: SmartGate



Amsterdam: Privium border passage

1. Satisfy individuality and permanence properties
2. Show high accuracy in NIST evaluations
3. Fast search (1:N comparisons) of large legacy databases

[http://www.homestaykorea.com/?document\\_srl=73667&mid=bbs\\_koreainfo\\_news](http://www.homestaykorea.com/?document_srl=73667&mid=bbs_koreainfo_news)

<https://tottnews.com/tag/smart-gates/>

<https://www.idemia.com/news/multi-biometrics-future-border-control-2016-04-21>



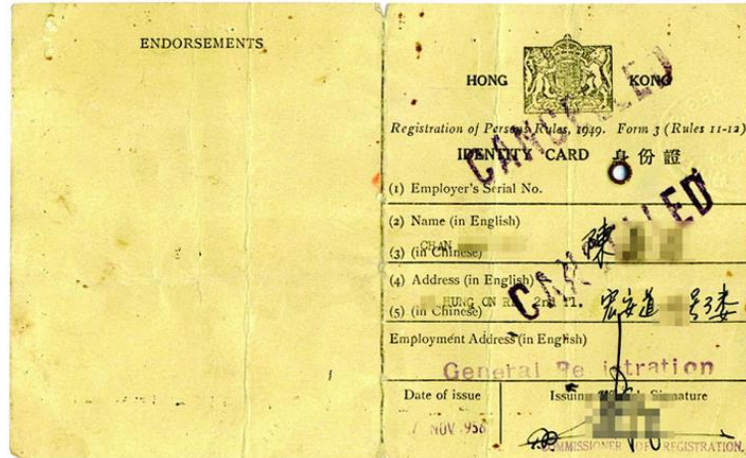
# Why Do We Need Biometrics?

We now live in a society, where people cannot be **trusted** based on ID documents, password and PIN



**How do we know who is entering card & PIN?**

# HK ID Cards: Paper to Smart Card



Paper Identity Card (1949)



Laminated Identity Card (1960)



Smart Identity Card (2003)



New Smart Identity Card (2018)

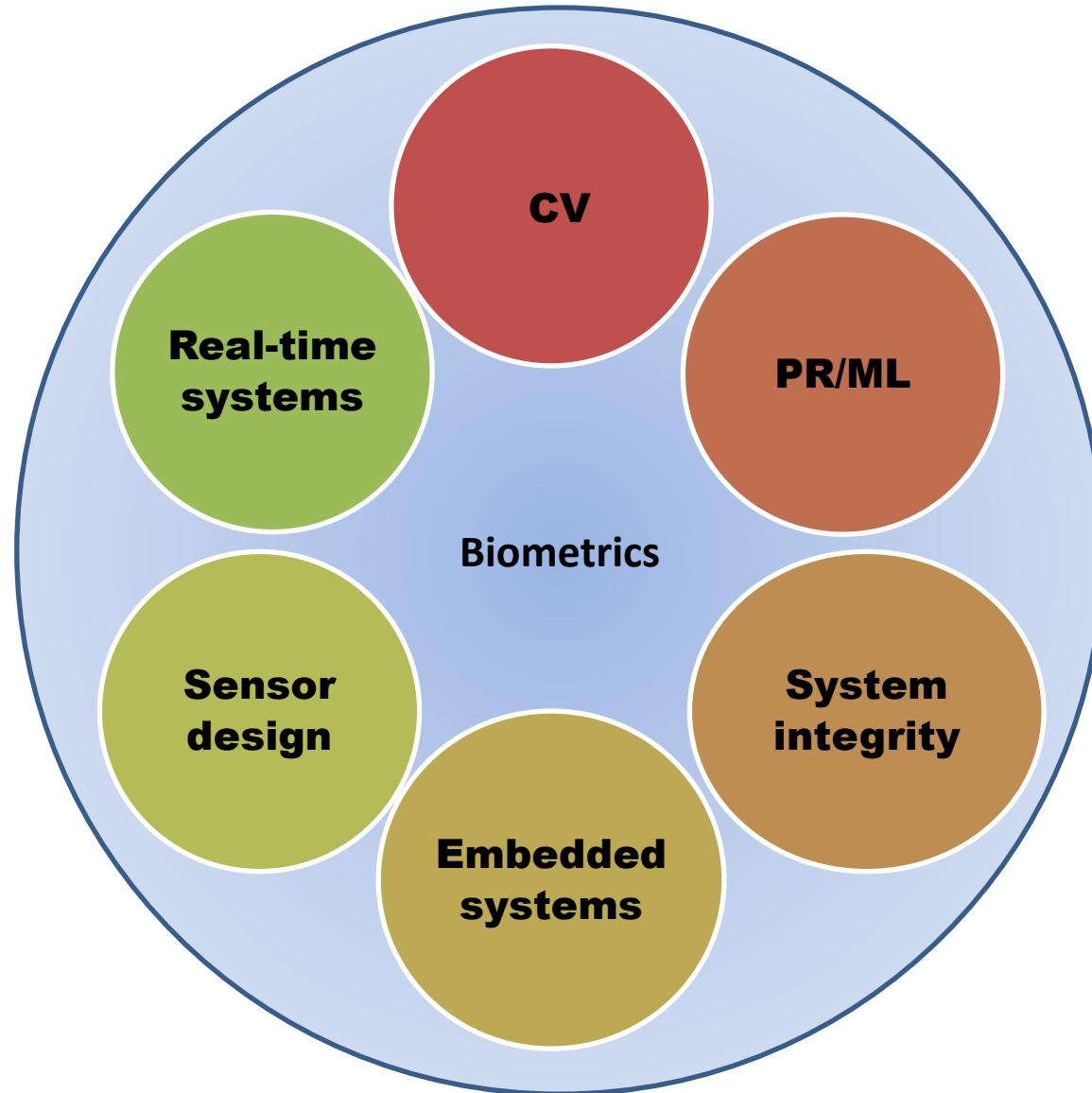
- Higher security
- More convenience

# Biometrics is About Applications

*Biometrics does not start with data and end with models/predictions. Rather, it starts with a problem faced by a real-world entity and ends with an action having an impact on that entity.*

***Biometrics is more than CV, ML and AI***

# Interdisciplinary Nature of Biometrics





# Biometric Deployments



**Requirements: Accuracy, throughput, cost, integration, usability, security, privacy**



**How did biometrics get its start?**

# Habitual Criminal Act (1869)

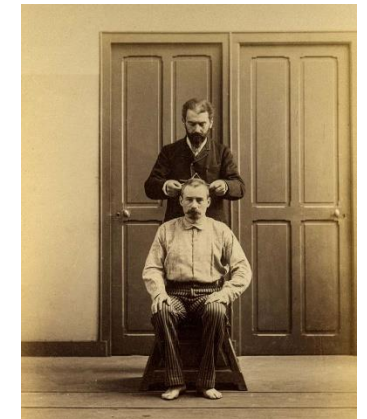
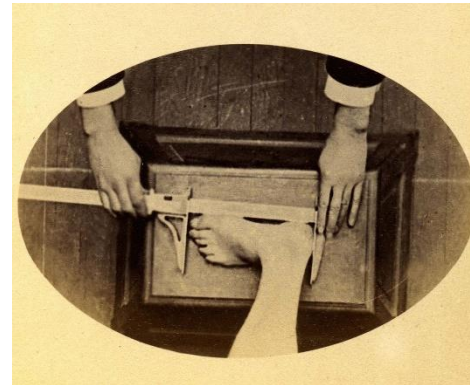
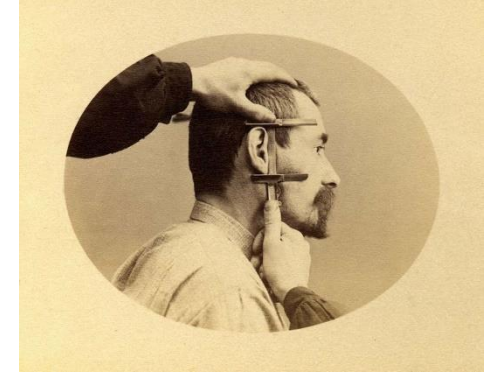
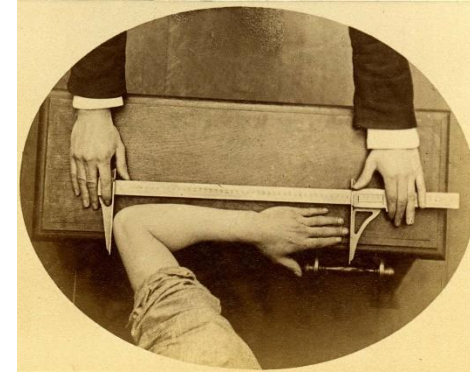
*“What is wanted is a means of classifying the records of **habitual criminals**, such that as soon as the particulars of the personality of any prisoner (whether description, measurements, marks, or photographs) are received, it may be possible to ascertain readily, and with certainty, whether his case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



# The Bertillon System that Cataloged Criminals by their Physical Measurements (1879)



Photographing a suspect in the courtyard of a Police Prefecture in Paris



Measurement of *unique features* of suspects; each coded as "small", "medium", "large"



# Fingerprints (1880)

*“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*

# Scotland Yard (1905)





# FBI (1924)

APPLICANT		LEAVE BLANK <i>Leave Blank</i>		TYPE OR PRINT ALL INFORMATION IN BLACK LAST NAME <i>Teacher, Theresa C.</i>		FBI		LEAVE BLANK <i>Leave Blank</i>	
SIGNATURE OF PERSON FINGERPRINTED		ALIASES AKA <i>Formerly: Theresa Smith</i>		O R I NY921940Z NYSTED Dept-FPU ALBANY, NY		DATE OF BIRTH DOB <i>12/31/70</i>			
RESIDENCE OF PERSON FINGERPRINTED <i>318 School Street Hometown, NY 11111</i>		CITIZENSHIP CTRY <i>US</i>		SEX RACE HT WT HAIR EYES <i>F W 5'7" 155 Gr Bro</i>		PLACE OF BIRTH POB <i>Ohio</i>			
DATE <i>5/02/02</i>		SIGNATURE OF OFFICIAL TAKING FINGERPRINTS <i>Leave Blank</i>		CLASS <i>Leave Blank</i>		REF <i>Leave Blank</i>			
EMPLOYER AND ADDRESS <i>(if applicable) Smart Falls Central School Dist Smart Falls, NY 11111</i>		REASON FINGERPRINTED <i>Leave Blank</i>		SOCIAL SECURITY NO. SSN <i>000-10-1111</i>		REASON FINGERPRINTED <i>Leave Blank</i>			
1. R. THUMB		2. R. INDEX		3. R. MIDDLE		4. R. RING		5. R. LITTLE	
6. L. THUMB		7. L. INDEX		8. L. MIDDLE		9. L. RING		10. L. LITTLE	
LEFT FOUR FINGERS TAKEN SIMULTANEOUSLY		L. THUMB		R. THUMB		RIGHT FOUR FINGERS TAKEN SIMULTANEOUSLY			

Tenprint card



Partial fingerprint from a crime scene

# Fingerprint Comparison (1960)



Courtesy: Michigan State Police



# Automated Fingerprint Identification Systems (AFIS)



**MSP (1989):** 700K tenprints in database; 5K rolled print searches; no latent search; 15K comparisons/sec.



**MSP (2018):** 4M tenprints in database; 650K rolled & 6K latent searches in 2017; search time:rolled (latent) prints = 5 sec (40)

- **Is the suspect in a criminal database?** Tenprint to tenprint search
- **Who left partial prints at crime scene?** Partial to tenprint search

# AUTOMATIC COMPARISON OF FINGER-RIDGE PATTERNS

(Trauring, Nature, 1963)

*“It is the purpose of this article to present, together with some evidence of its feasibility, a method by which decentralized automatic identity verification, **such as might be desired for credit, banking or security purposes**, can be accomplished through automatic comparison of the minutiae in finger-ridge patterns.”*

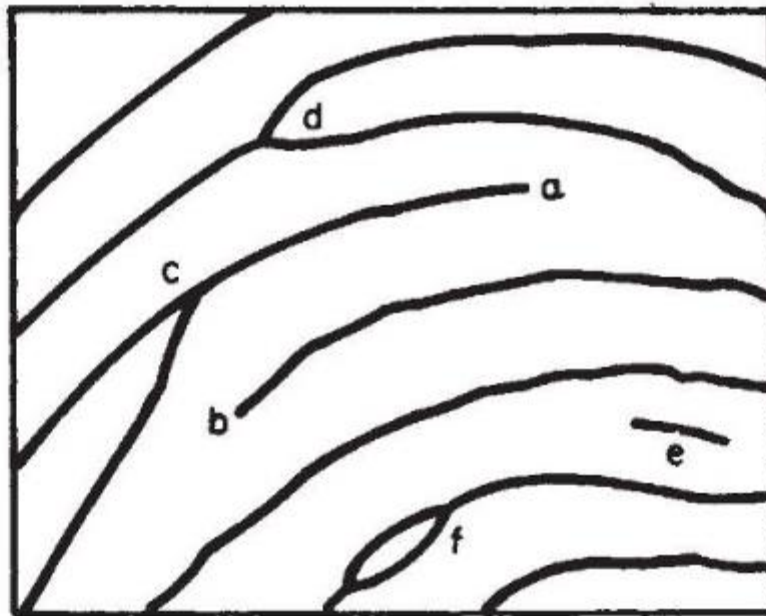
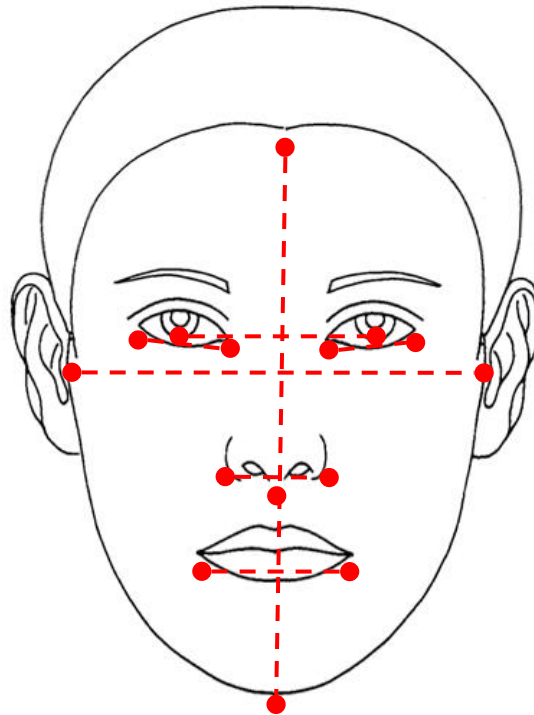


Fig. 1. Portion of fingerprint pattern (diagrammatic, enlarged) after Galton, showing minutiae. *a* and *b* are ridge ends, *c* and *d* are ridge branchings or valley ends, *e* is an island, and *f* is an enclosure. The ridge end and valley end are the principal minutia types, accounting for almost all minutia occurrences

# Face Recognition (Bledsoe, 1966)

"This recognition problem is made difficult by the great variability in head rotation and tilt, lighting intensity and angle, facial expression, aging, etc." *Bledsoe, Chan and Bisson (1966)*



Used 20 inter-point  
distances for matching

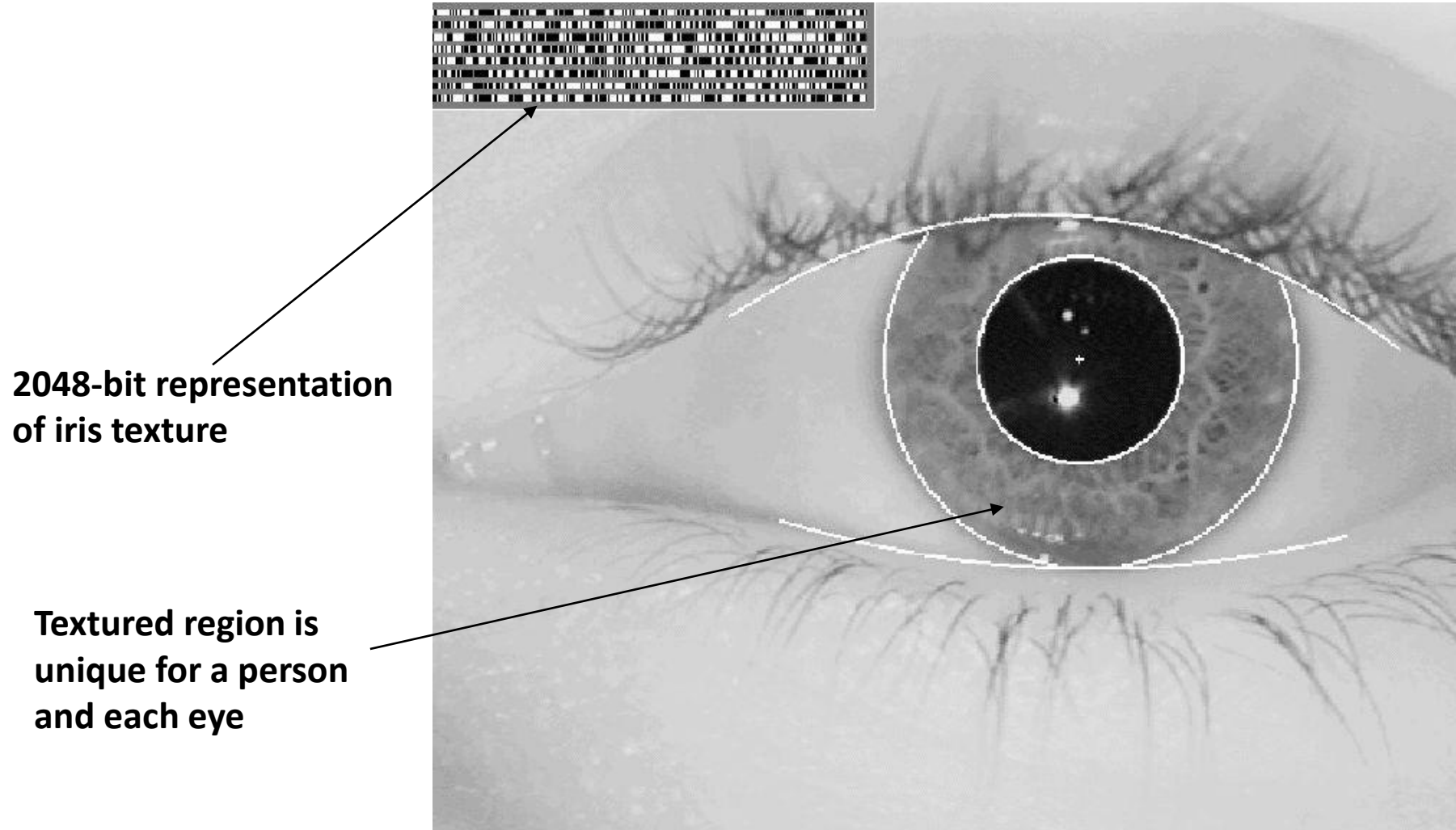


# Identimate (1972)



First commercial use of biometrics

# Iris Recognition (Daugman, 1993)



*J. Daugman, "High confidence visual recognition of persons by a test of statistical independence," IEEE Trans. PAMI, 1993.*

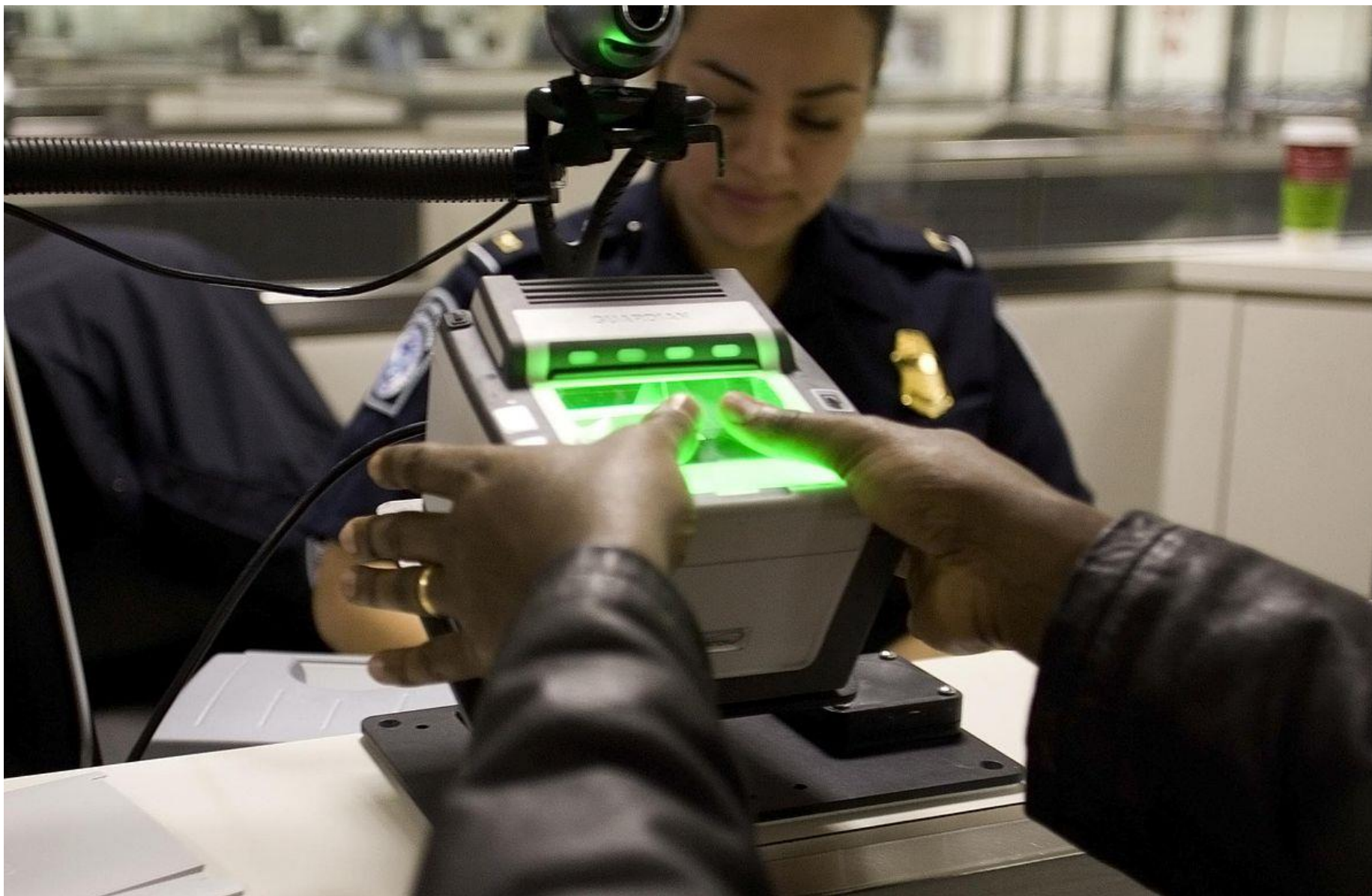
# **Biometric Milestones**

# 9/11 Terrorist Attacks (2001)





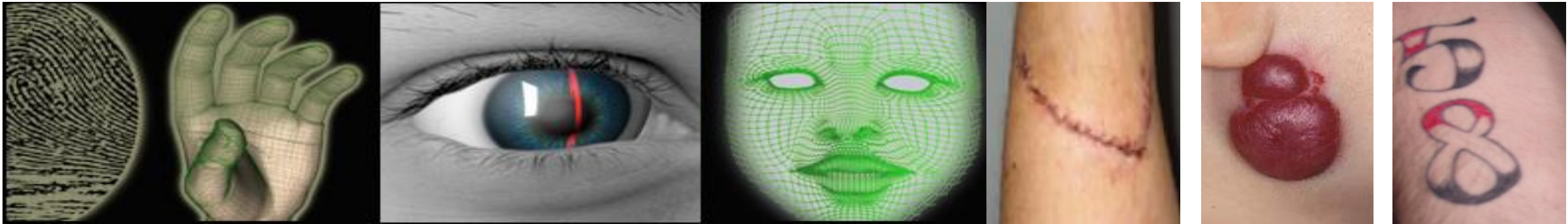
# US-VISIT (2003)



# Walt Disney Theme Park (2005)



# FBI Next Generation Identification (2008)



**First AFIS in 1980; IAFIS launched in 1999; use of soft biometrics (SMT)**

*[http://www.fbi.gov/about-us/cjis/fingerprints\\_biometrics/ngi/ngi2/](http://www.fbi.gov/about-us/cjis/fingerprints_biometrics/ngi/ngi2/)*



# India's National ID: Aadhaar (2009)



The advertisement features a large orange background with a fingerprint pattern. On the left, a full Aadhaar letter is shown, and on the right, a hand uses scissors to cut out a smaller Aadhaar card. The letter and card both display the name Sapna Singh, her address, and her Aadhaar number 4444 5555 6666. The card also includes a photo and a QR code.

**भारतीय विशिष्ट पहचान प्राधिकरण**  
**भारत सरकार**  
Unique Identification Authority of India  
Government of India

Enrollment No.: 1234/56789/01234

To  
सपना सिंह  
Sapna Singh  
D/O Pawan Singh  
A/B-34, Budhnagar  
Inderpur  
New Delhi - 110012

Date: 06/06/2012

AA123456789ZZ

आपका आधार क्रमांक / Your Aadhaar No. :  
**4444 5555 6666**

**आधार — आम आदमी का अधिकार**

भारत सरकार  
GOVERNMENT OF INDIA

सपना सिंह  
Sapna Singh  
जनम वर्ष / Year of Birth : 1990  
महिला / Female

4444 5555 6666

**आधार — आम आदमी का अधिकार**

सपना सिंह  
Sapna Singh  
जनम वर्ष / Year of Birth : 1990  
महिला / Female

4444 5555 6666

**आधार — आम आदमी का अधिकार**

**Unique Identification Authority of India**  
Planning Commission, Government of India

**ALWAYS CARRY YOUR AADHAAR WITH YOU**  
**and avail benefits of various services**

Cut this portion of Aadhaar letter  
and carry it with you.  
(You may get it laminated too)

Aadhaar : your proof of identity and proof of address for

- opening a Bank account
- getting a Mobile connection
- getting a LPG connection
- AADHAAR helps in proving ID during Train travel
- ...and many more services

**AADHAAR**  
Aam Aadmi Ka Adhikaar

[www.uidai.gov.in](http://www.uidai.gov.in)

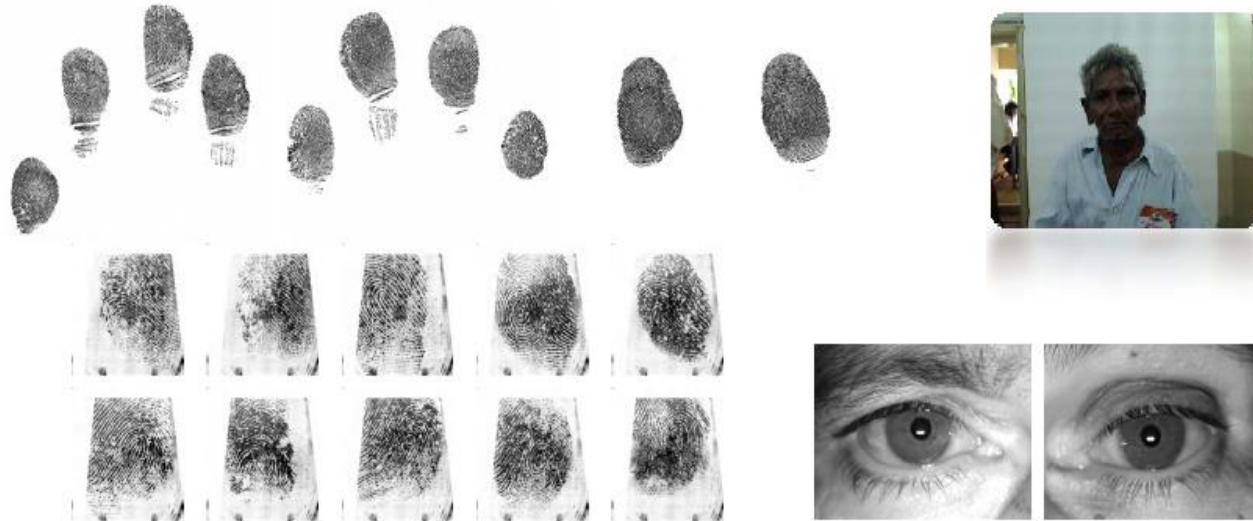
***“To empower residents of India with a unique identity and a digital platform to authenticate anytime, anywhere.”***



# Enrollment



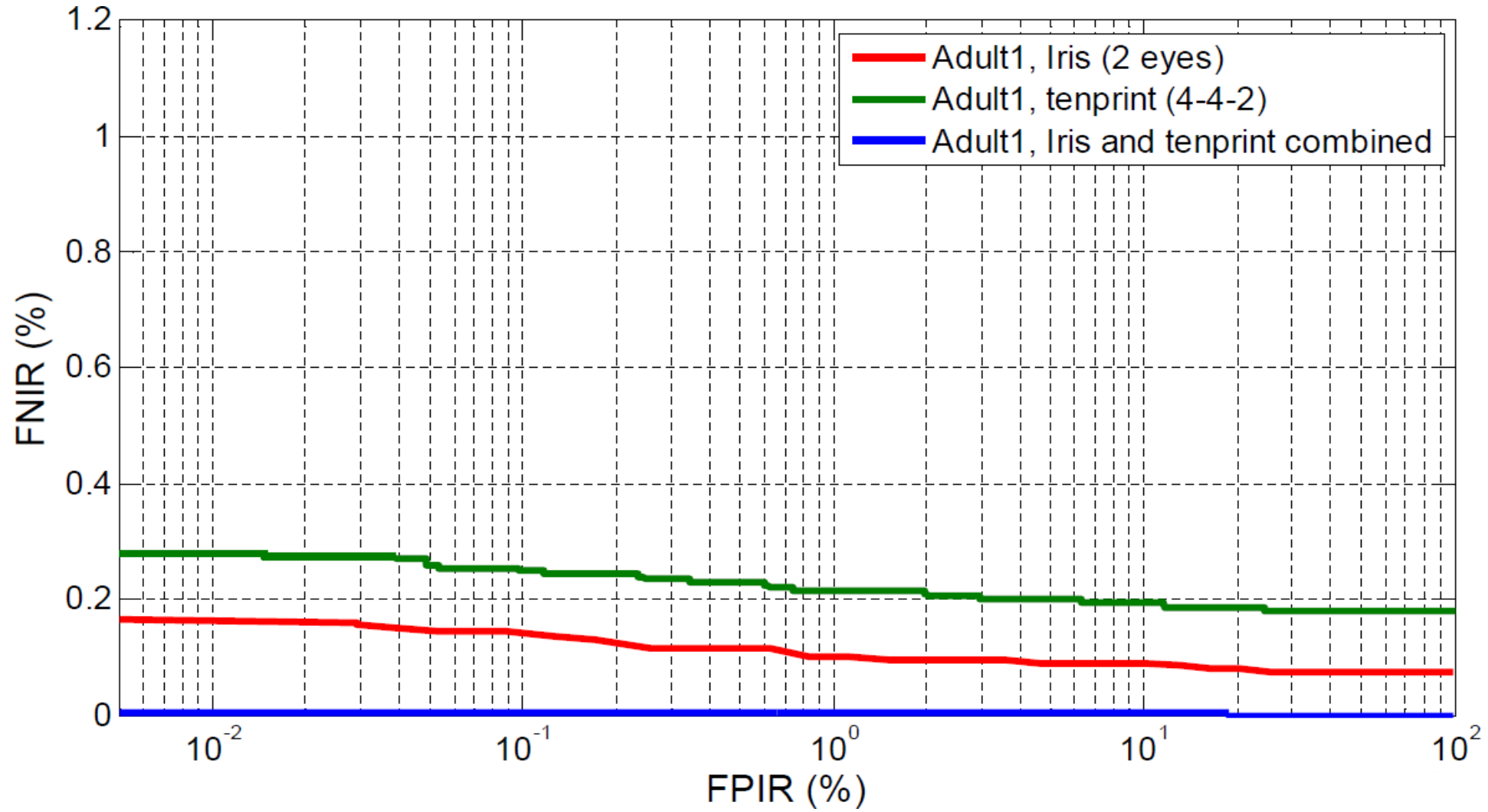
**Minimal documentation needed**



**Over 1.3 billion Indian residents have been enrolled (age > 5 yrs.)**

**Aadhaar: fingerprint & iris are core biometrics, but growing use of face**

# Fusion for De-duplication



- **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



[https://uidai.gov.in/aadhaar\\_dashboard/auth\\_trend.php](https://uidai.gov.in/aadhaar_dashboard/auth_trend.php)

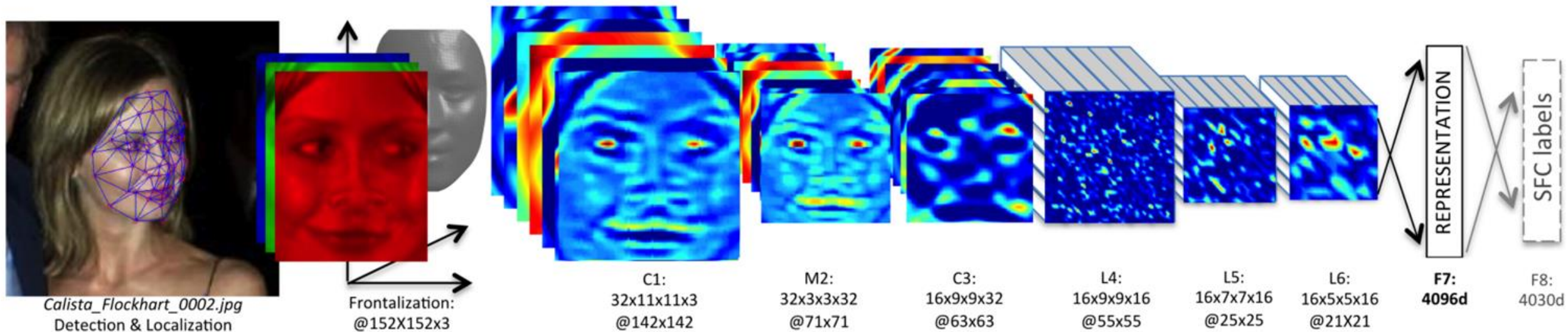
**65 million authentications/day**

# TouchID (2013)





# Deepface (2014)



**Multiple layers of neurons stacked together and connected to a small area in previous layer (120M parameters)**

# FaceID (2017)



# In-display Fingerprint Sensor (2018)



# Match on Card (2022)

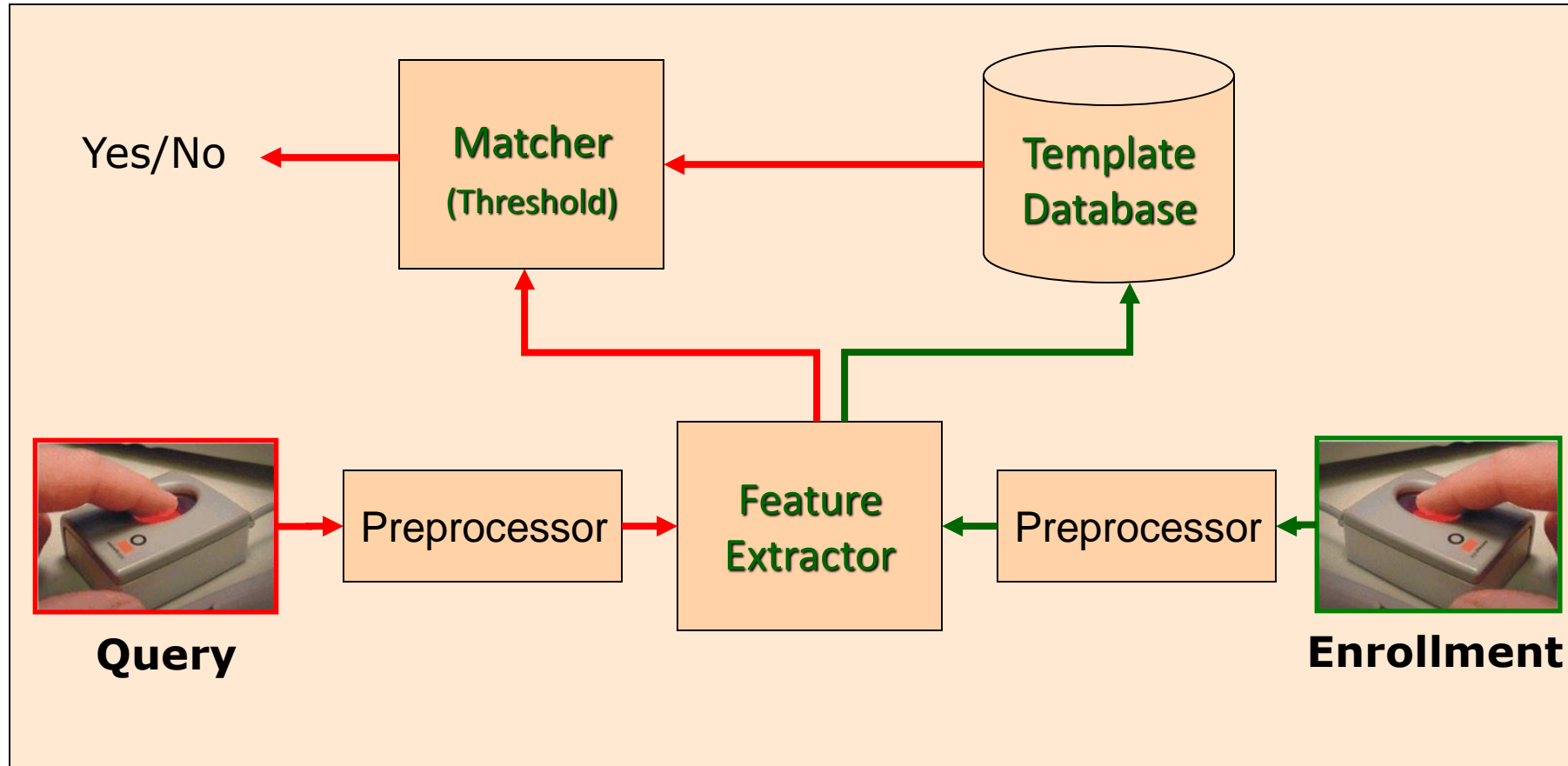


**Sensor, feature extractor & matching all reside on the card**



# How Do Biometric Systems Work?

# Fingerprint Recognition System

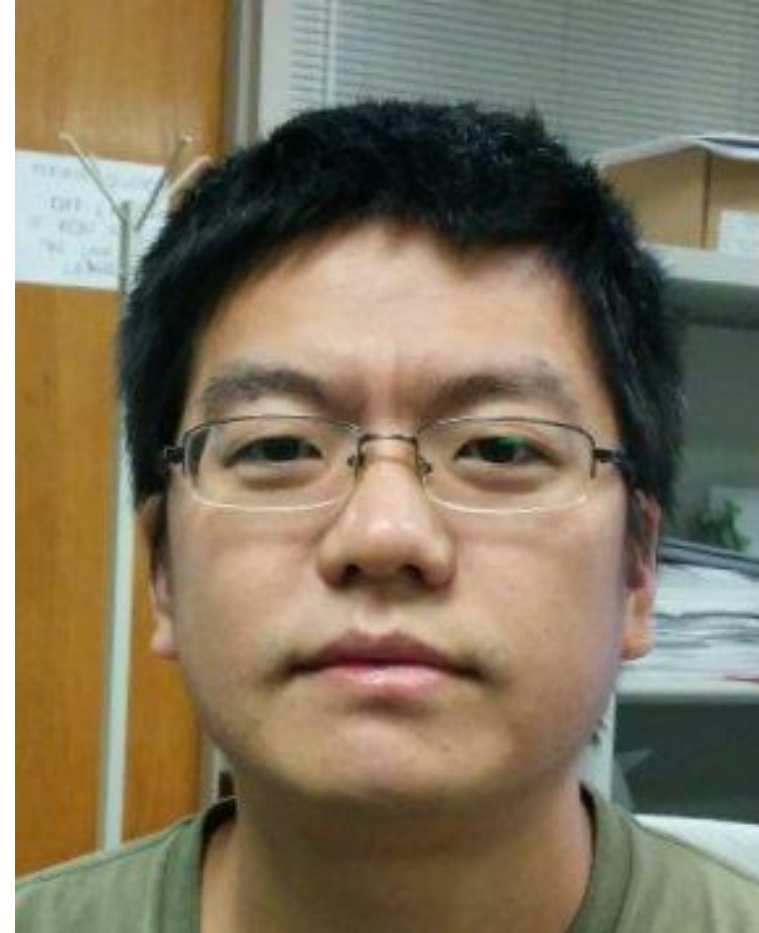


- **Authentication:** Claim of identity made
- **Identification:** No claim of identity made

# Essence of Biometrics: Pairwise Similarity



**Query face**



**Enrolled face**

**Challenges: (i) features (representation); (ii) similarity measure**

# Face Search (1:N Comparisons)



Probe

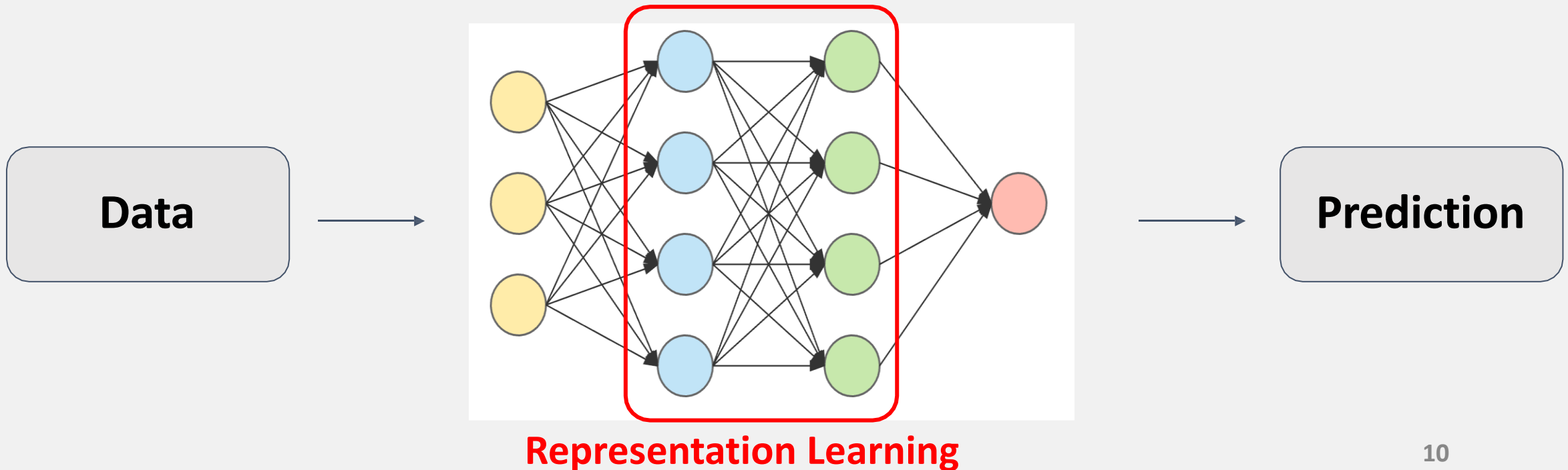
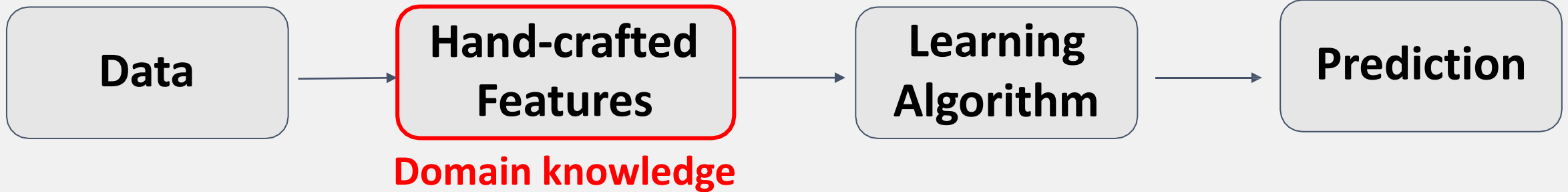


Gallery

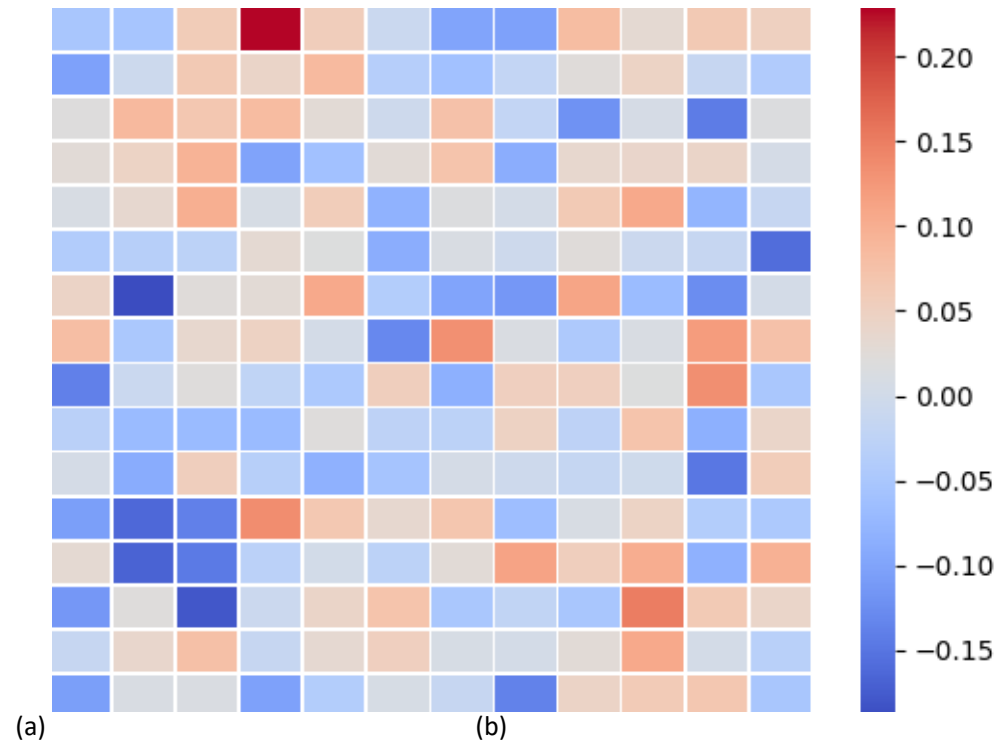
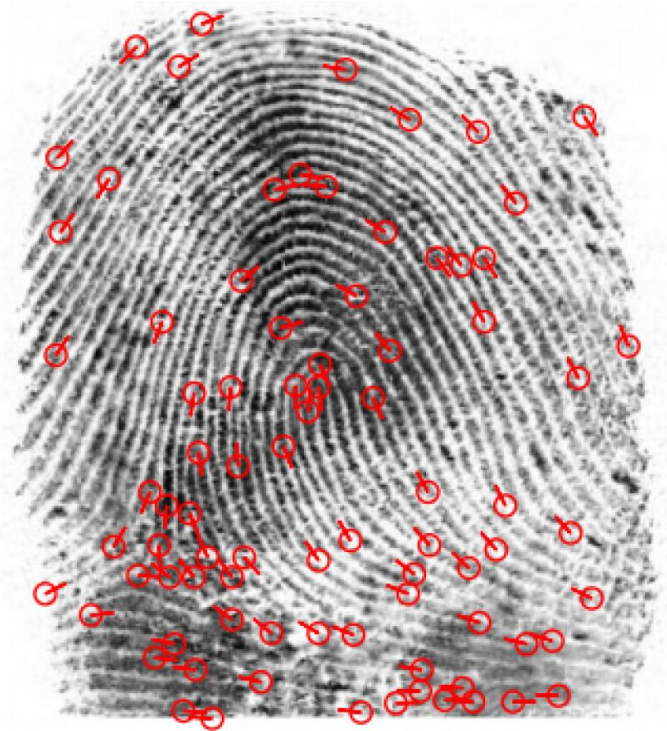
Probe may or may not be present (enrolled) in the gallery



# Feature Extraction (Representation)

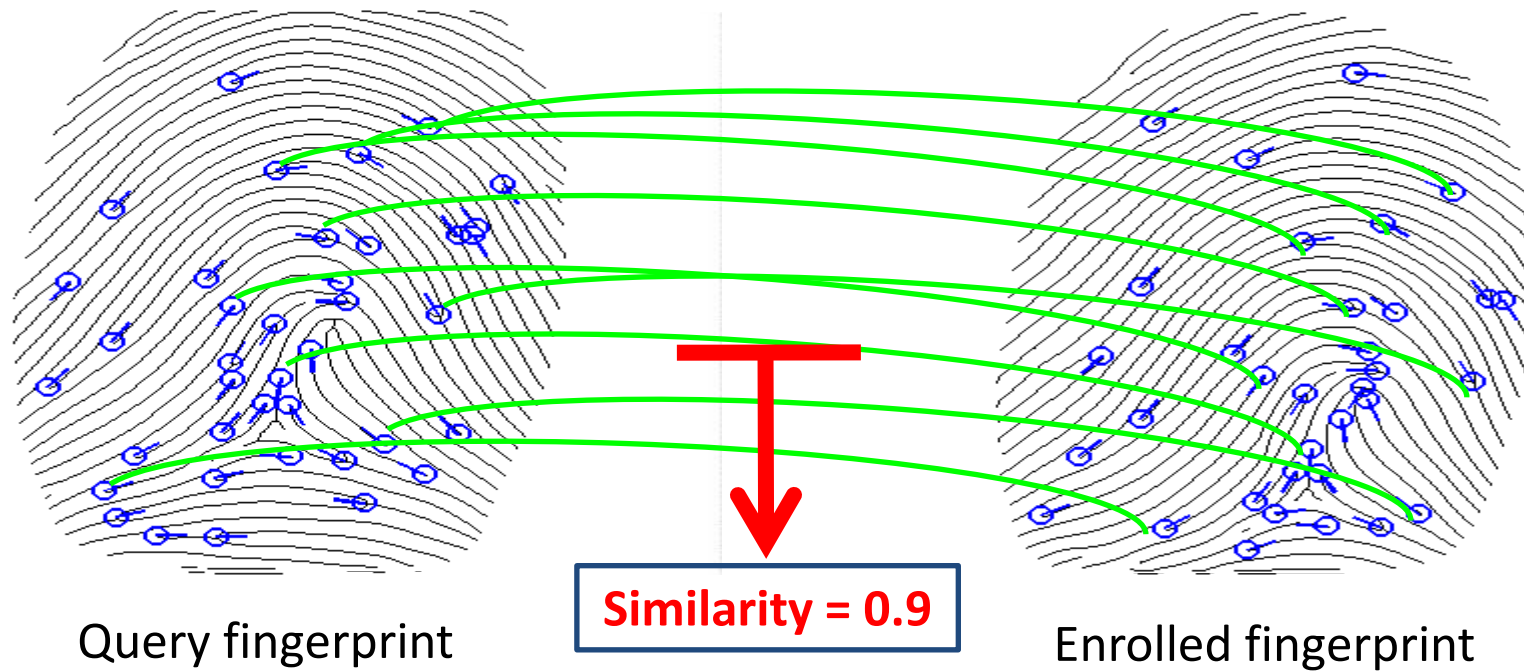


# Fingerprint Representation



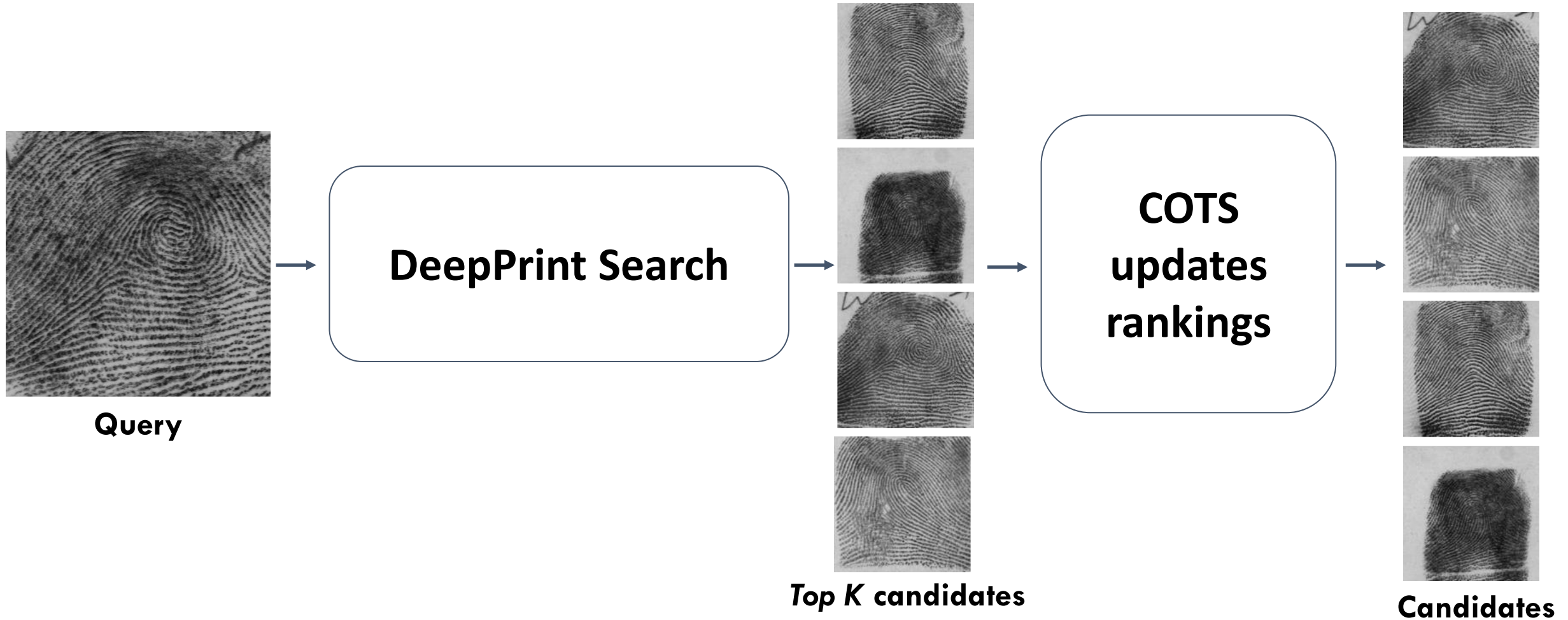
**Minutiae representation vs. 192-dim embeddings**

# Fingerprint Minutiae Matching



**Matching is accurate but slow**

# Representation Fusion



**Fusion of data-driven and knowledge-driven representations: Rank-1 improves from 99.45% to 99.48%**



# SOTA Performance (Constrained Acquisition)

## 1:1 Comparison; FAR = 0.001%

Fingerprint: TAR = 99.56% (Verifinger V12.3)

Iris: TAR = 99.43% (NIST IREX IX)

Face: TAR = 99.83% (NIST FRVT 2022)

## 1:N Comparison; FPIR = 0.001

Fingerprint (10 fingers): FNIR = 0.001 (5M gallery)

Fingerprint (1 finger): FNIR = 0.019 @ (100K gallery)

Iris (Both eyes): FNIR = 0.0035 (500K gallery)

Face: FNIR = 0.03 (12M gallery)

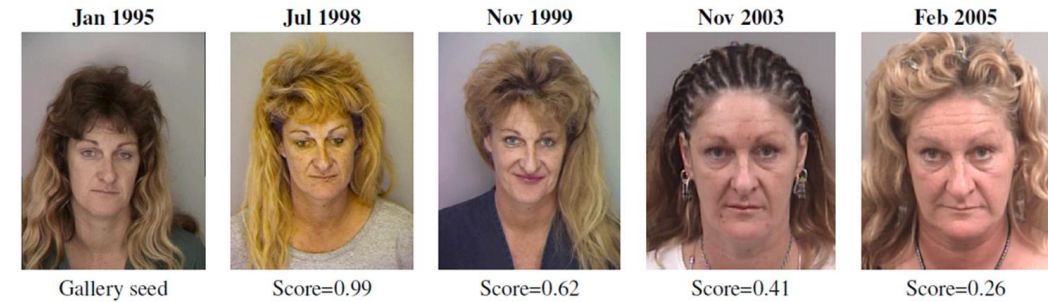
[1] NIST FRVT 1:N Identification: <https://pages.nist.gov/frvt/html/frvt1N.html>

[2] NIST FpVTE: <https://nvlpubs.nist.gov/nistpubs/ir/2014/NIST.IR.8034.pdf>

[3] NIST IREX 10 Identification Track: <https://pages.nist.gov/IREX10/>

# Why do Biometric Systems Make Mistakes?

- Limited capacity of biometric trait/representation
- Non-robust matcher
- Large Intra-person variability
- Large inter-person similarity
- Noisy biometric samples
- Poor interaction with biometric reader

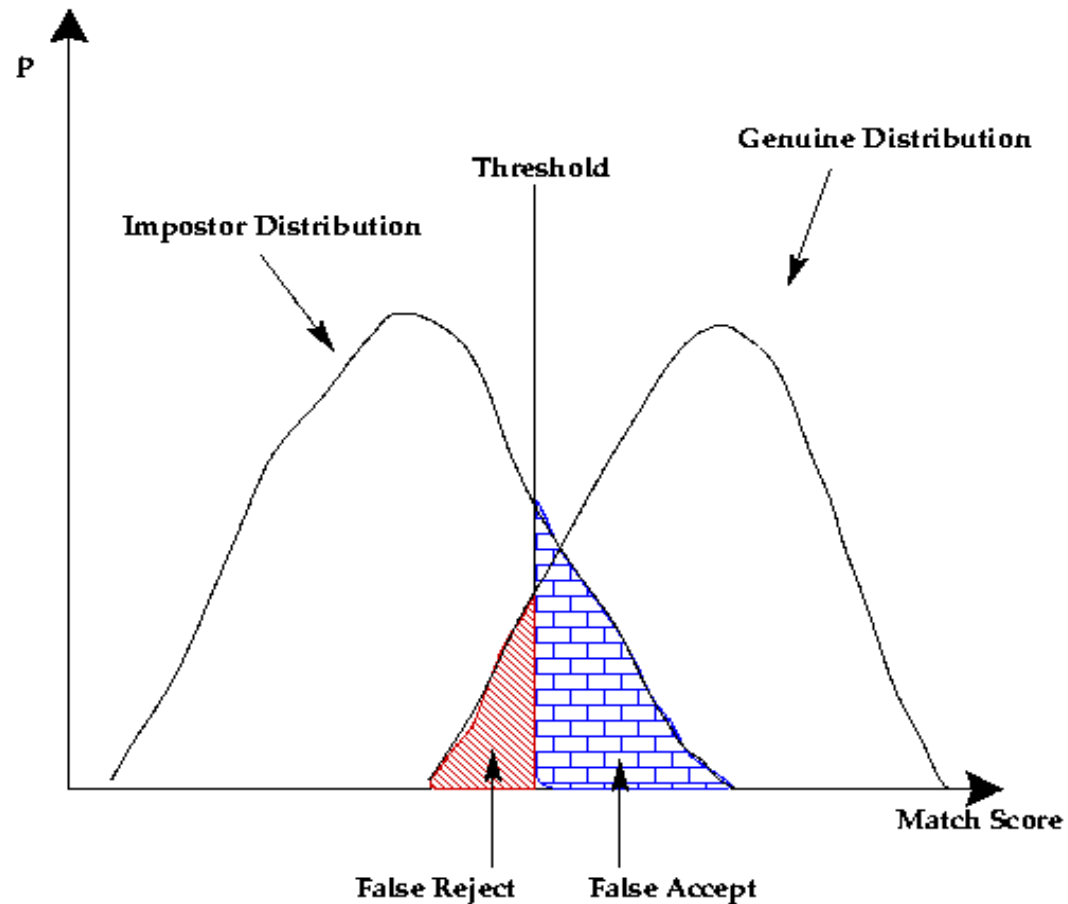


**Clear:** expedited airport security program  
Attended, large throughput, annual fee



**Amazon One:** expedited payment in Whole Foods,..  
Unattended, fusion, unexpected customer behavior

# Similarity Score Distributions



- **FAR: Proportion of wrongful claims of identity that are incorrectly confirmed**
- **FRR: Proportion of transactions with truthful claims of identity that are incorrectly denied**
- **Threshold: A value which satisfies the specified FAR**
- **RoC: Plot of true positive rate (TPR) vs. false positive rate (FPR) at various threshold settings**

# Face Image Quality vs. Recog. Performance



LFW (2009)



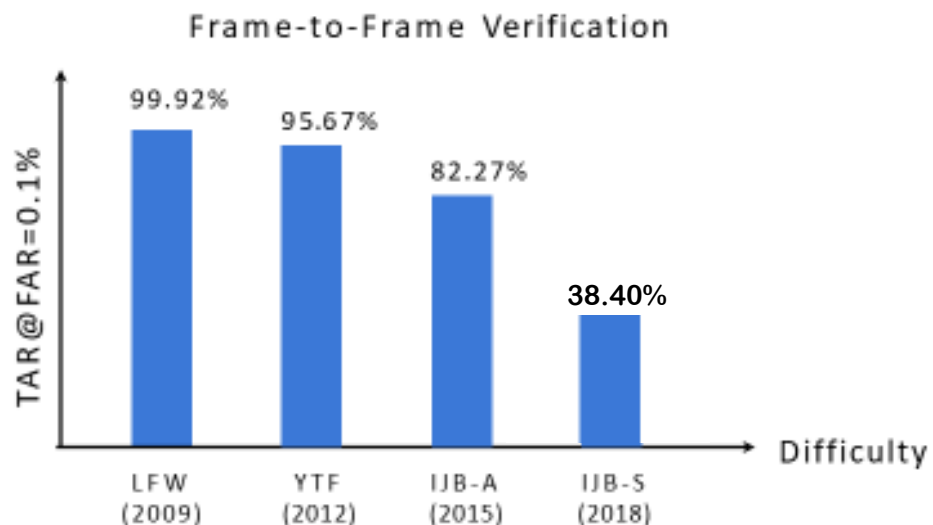
YTF (2012)



NIST IJB-A (2015)



NIST IJB-S (2018)



	Gallery Size	Rank1	Rank5
IJB-A	112	97.5	98.4
IJB-S (S2B)	202	60.5	66.0
<b>IJB-S (S2B) With DA</b>	<b>202</b>	<b>64.5</b>	<b>71.1</b>

DA denotes 'data augmentation with synthetic data'



# Wrongfully Accused by an Algorithm





(a) Robert Williams

(a)

MICHIGAN STATE POLICE  
INVESTIGATIVE LEAD REPORT  
LAW ENFORCEMENT SENSITIVE

THIS DOCUMENT IS NOT A POSITIVE IDENTIFICATION. IT IS AN **INVESTIGATIVE LEAD ONLY** AND IS **NOT** PROBABLE CAUSE TO ARREST. FURTHER INVESTIGATION IS NEEDED TO DEVELOP PROBABLE CAUSE TO ARREST.

BID DIA Identifier: BID-39641-19	Requester: CA Yager, Rathe
Date Searched: 03/11/2019	Requesting Agency: Detroit Police Department
Digital Image Examiner: Jennifer Coulson	Case Number: 1810050167
	File Class/Crime Type: 3000

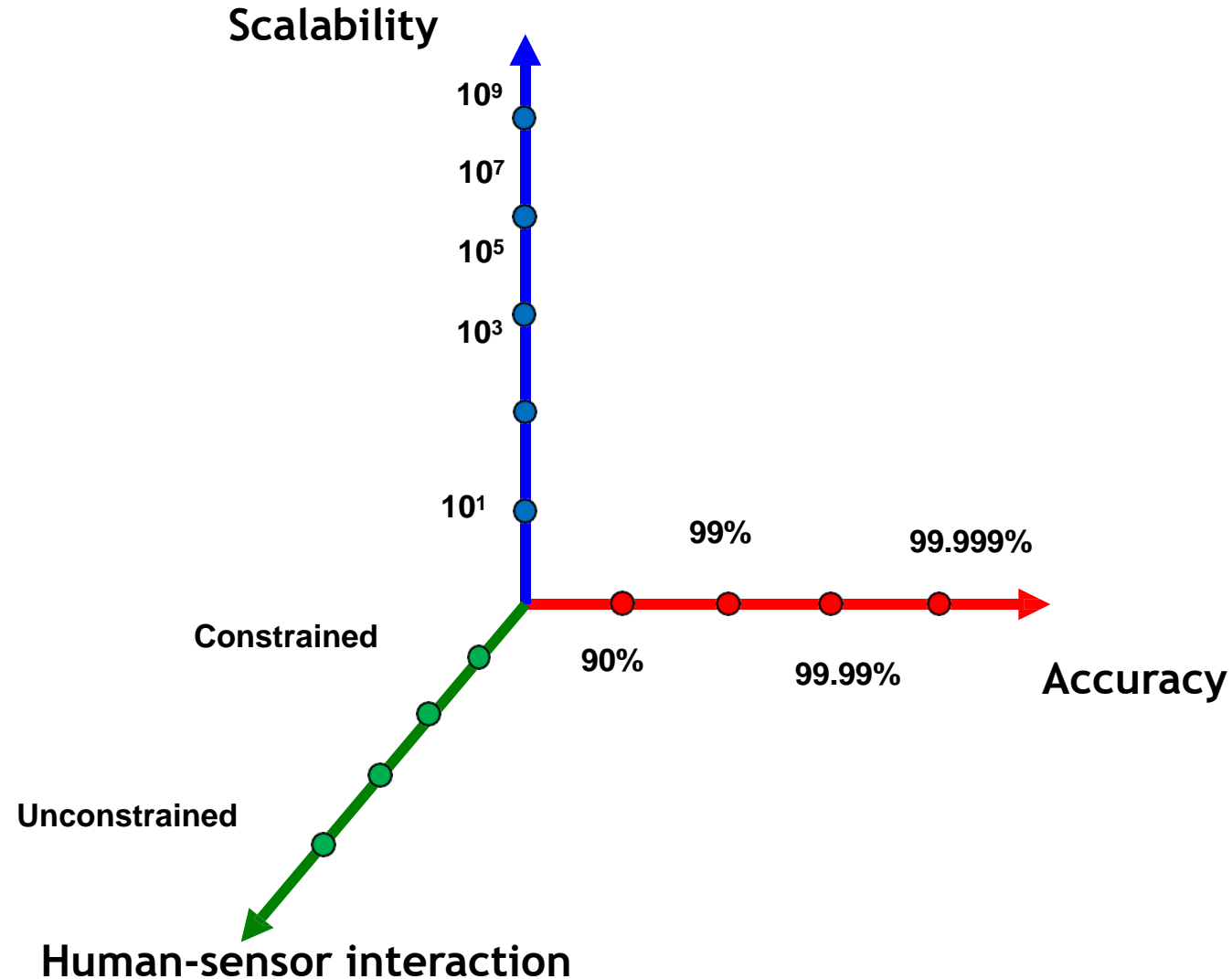
Probe Image	Investigative Lead
	

(b) Investigative Lead Report

FR system wrongfully identified (a) Robert William when the CCTV frame in (b) was searched against a 49M gallery; forensic experts did not conduct a manual examination of the candidate list

# **Challenges Ahead**

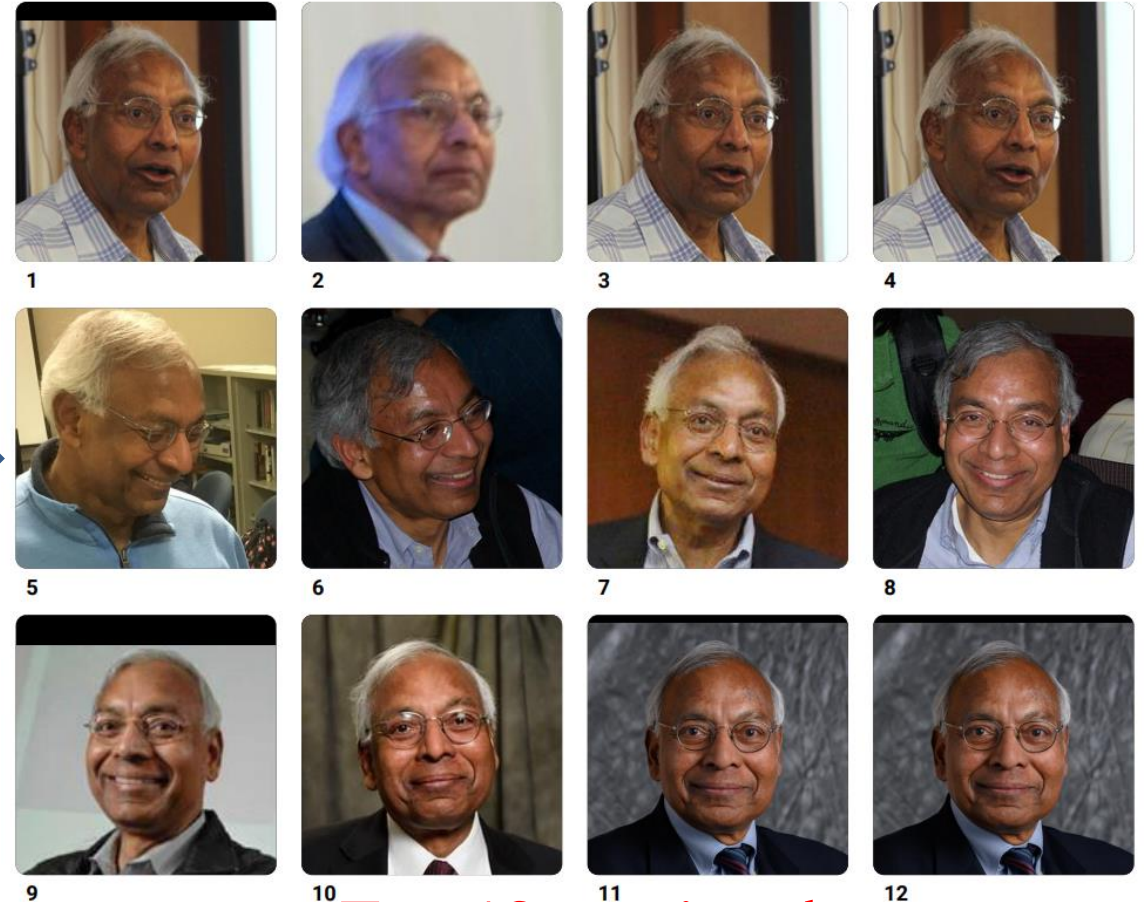
# Design Scalable, Accurate & Trusted Biometric Systems



# Unconstrained Face Search (*Clearview.AI*)



**Probe**

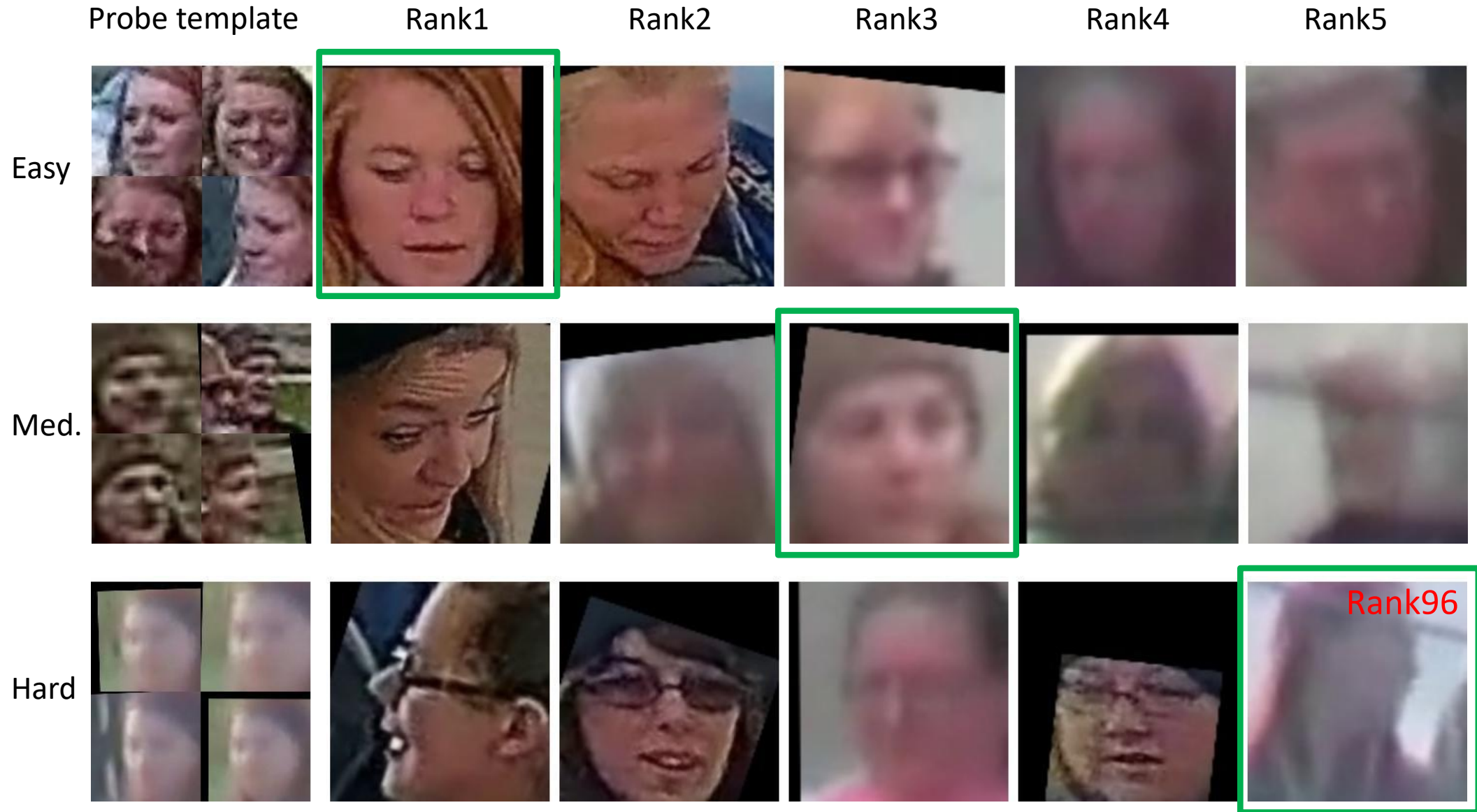


**Top 12 retrievals**

**Gallery: 20 billion face images**



# Improve Face Recognition in Video



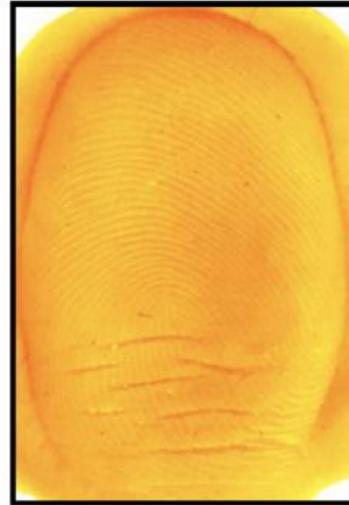
# Presentation Attacks (Spoofs)



**Ecoflex**



**Wood Glue**



**PlayDoh**



**Monster Latex**



**Gelatin**



**Latex Body  
Paint**



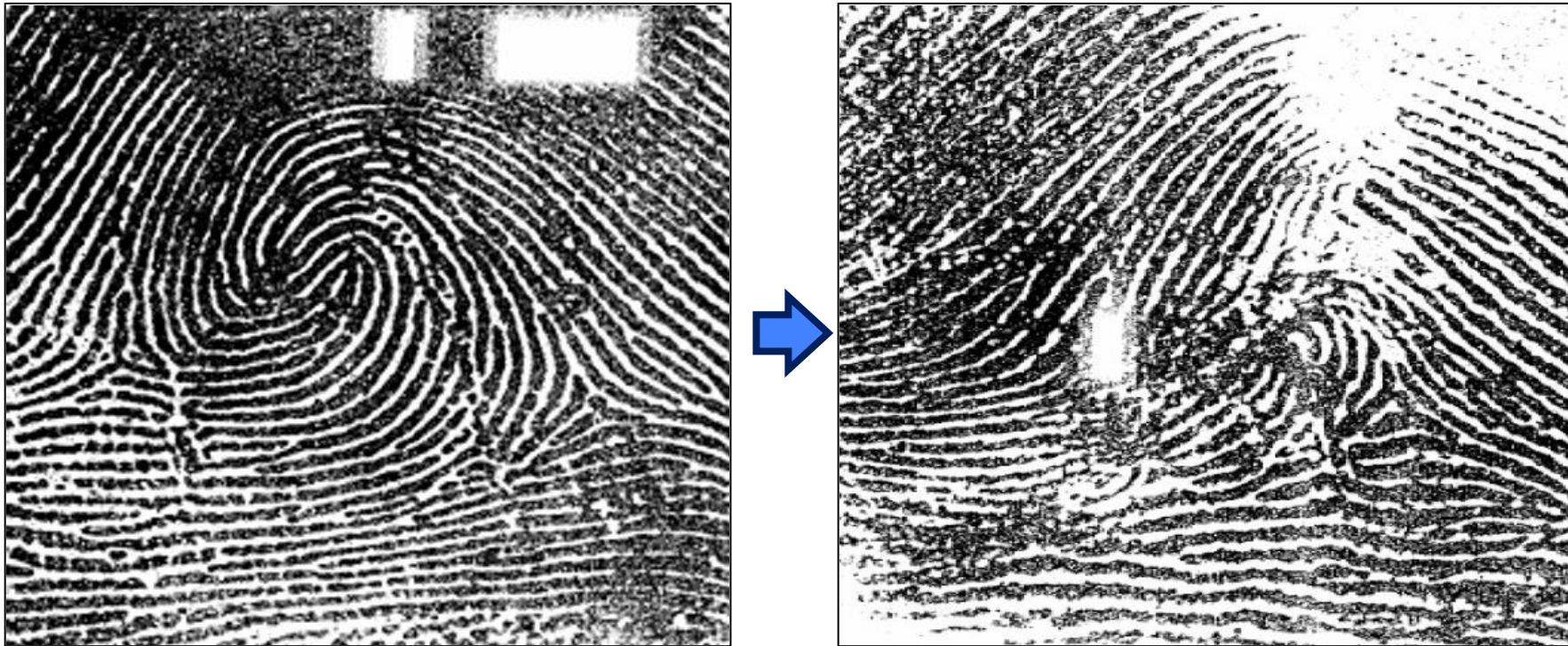
**2D Printed  
Paper**



**2D Paper  
Transparency**



# Alteration of Biometric Modality



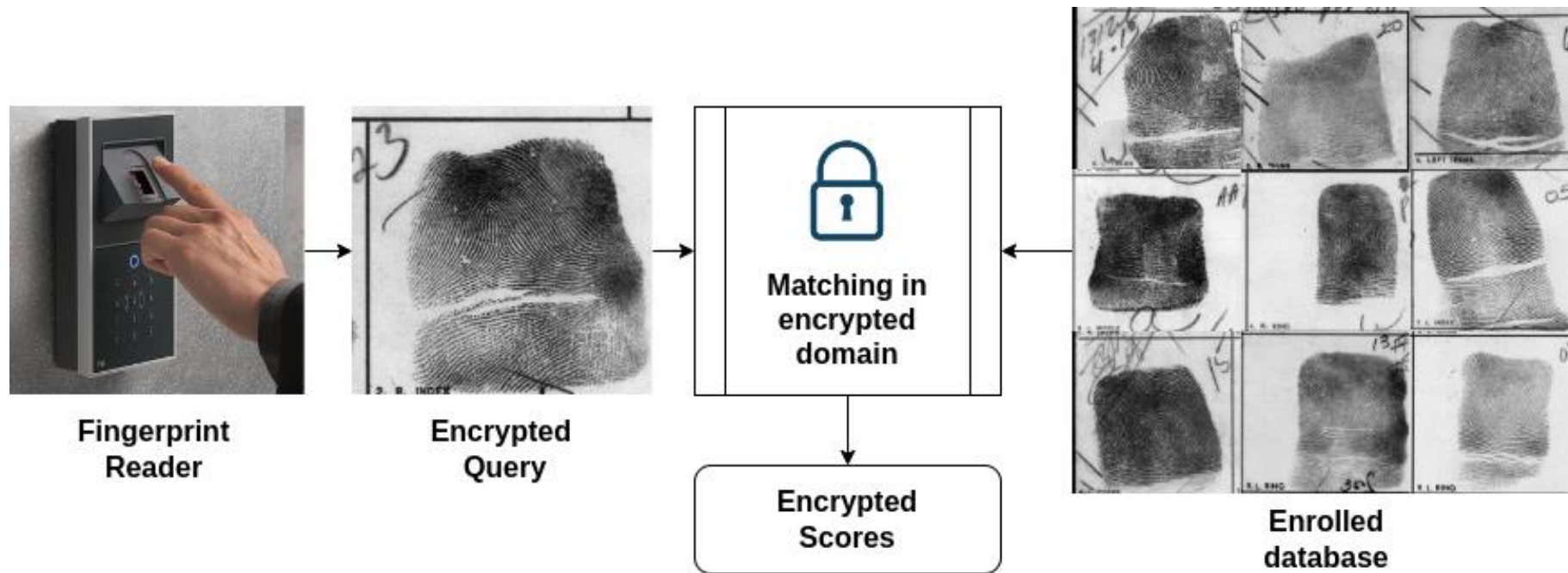
**Winkler (1933) changed double-loop fingerprint to left loop to evade identification**

# User Consent and Biometric Data Privacy

- **General Data Protection Regulation (GDPR); May 25, 2018**
  - **Personal Data:** *“any information that relates to an individual who can be directly or indirectly identified. This includes ethnicity, gender and biometric data.”*
  - **Seven data protection principles:** (i) Lawfulness, fairness and transparency; (ii) purpose limitation; (iii) storage limitation; (iv) Integrity and confidentiality
- **How do researchers get access to biometric data?**



# Privacy Preserving Authentication



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

# Real or Synthetic Fingerprint Images



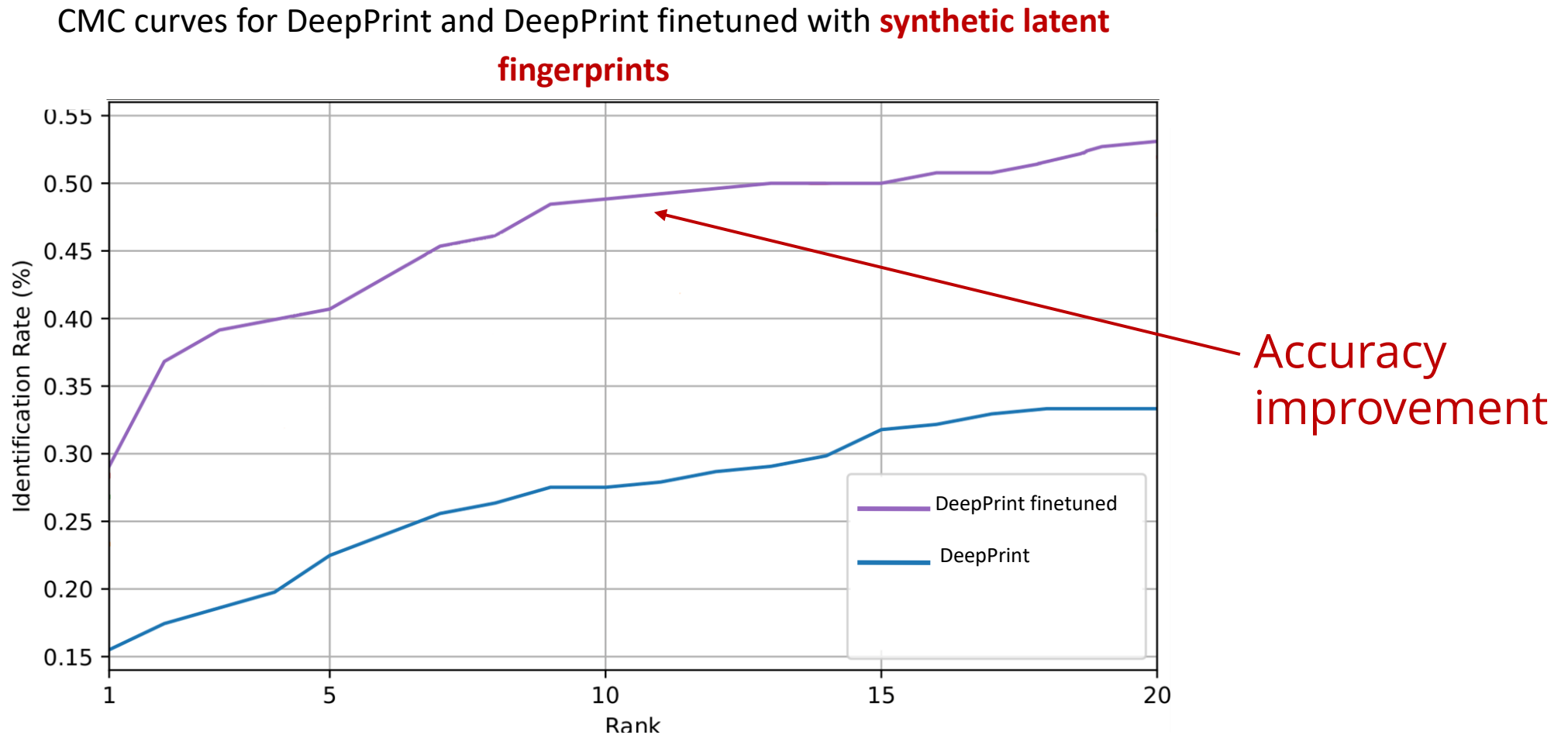


# Real or Synthetic Fingerprint Images





# Data Augmentation: Accuracy improvement



Evaluated on NIST SD27 (1:N experiment)  
DeepPrint: <https://arxiv.org/abs/1909.09901>



# Take Home Message

- Biometrics is intertwined with applications: law enforcement and forensics; access control; payment and benefits; civil registration; travel and immigration,...
- Attention to application requirements
- Face, fingerprint and iris modalities will continue to dominate
- Despite success of biometrics, it is not a solved problem
- Challenges: physical spoofs, data privacy, unconstrained recognition, consequences of incorrect decision, billion-scale search,...