50 Years of Biometric Research:

Almost

~~The~~ Solved, The Unsolved, and The Unexplored

Anil Jain
Michigan State University

June 5, 2013

Keynote Talk Delivered at the International Conf. on Biometrics, Madrid, Spain, June 5, 2013

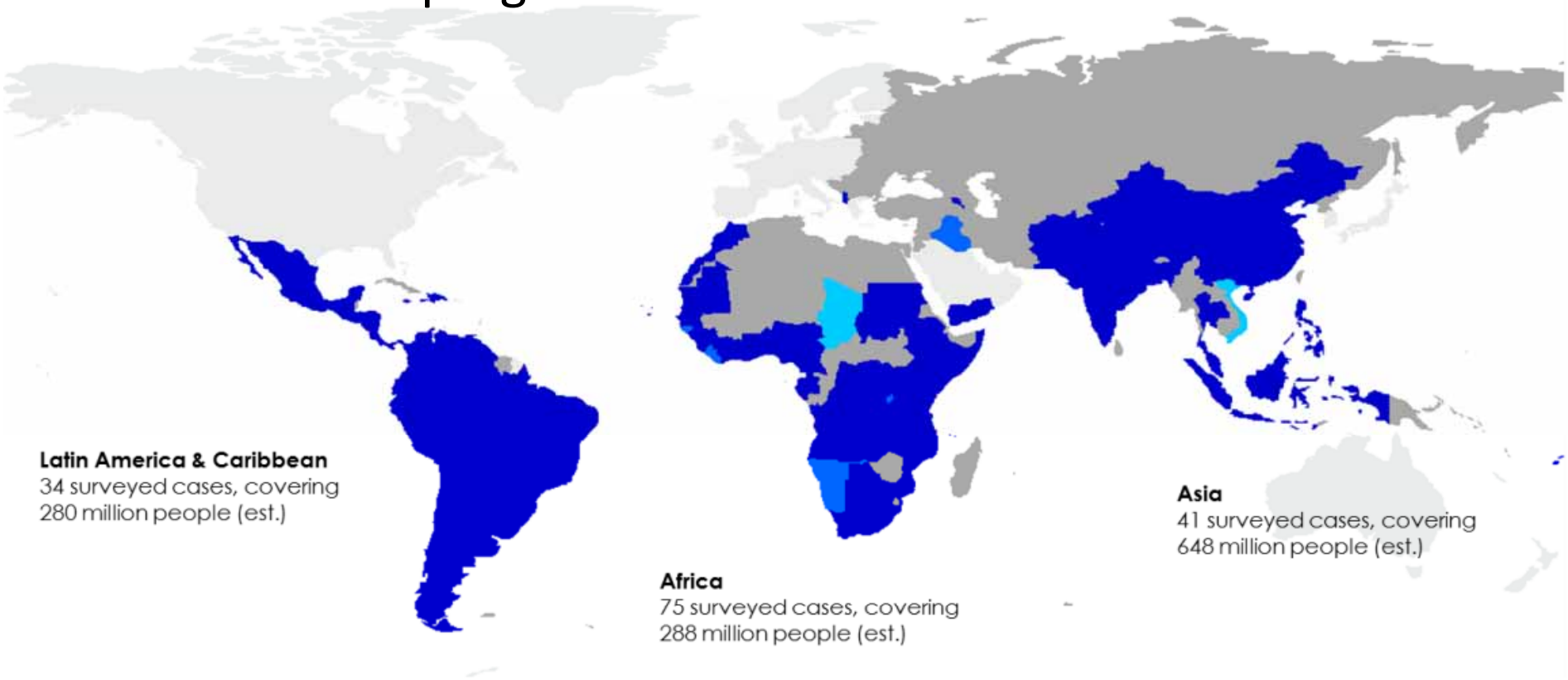
50 Years of Biometrics Research

- **Fingerprint**
  - M. Trauring, "On the Automatic Comparison of Finger Ridge Patterns", *Nature,* vol. 197, pp. 938–940, 1963
- **Voice**
  - S. Pruzansky, "Pattern-Matching Procedure for Automatic Talker Recognition", *J. Acoustic Society of America,* vol. 35, pp. 354–358, 1963
- **Face**
  - W. W. Bledsoe, "Man-Machine Facial Recognition", Tech. Report PRI 22, Panoramic Res. Inc., 1966
  - T. Kanade, "Picture Processing System by Computer Complex and Recognition of Human Faces", Doctoral Dissertation, Kyoto University, 1973
- **Hand geometry**
  - R.H. Ernst, "Hand ID System", *US Patent No. 3576537*, 1971
- **Iris**
  - L. Flom and A. Safir, "Iris Recognition System", *US Patent 4641349 A*, 1987
  - J. G. Daugman, "High Confidence Visual Recognition of Persons by a Test of Statistical Independence", *IEEE Trans. PAMI, vol. 15, pp. 1148–1160,* 1993

1960s: Beginnings of research in AI, pattern recognition & image processing

Identification for Development: The Biometrics Revolution

Over 1 billion people have been covered by biometric identification programs in the Low Middle Income Countries

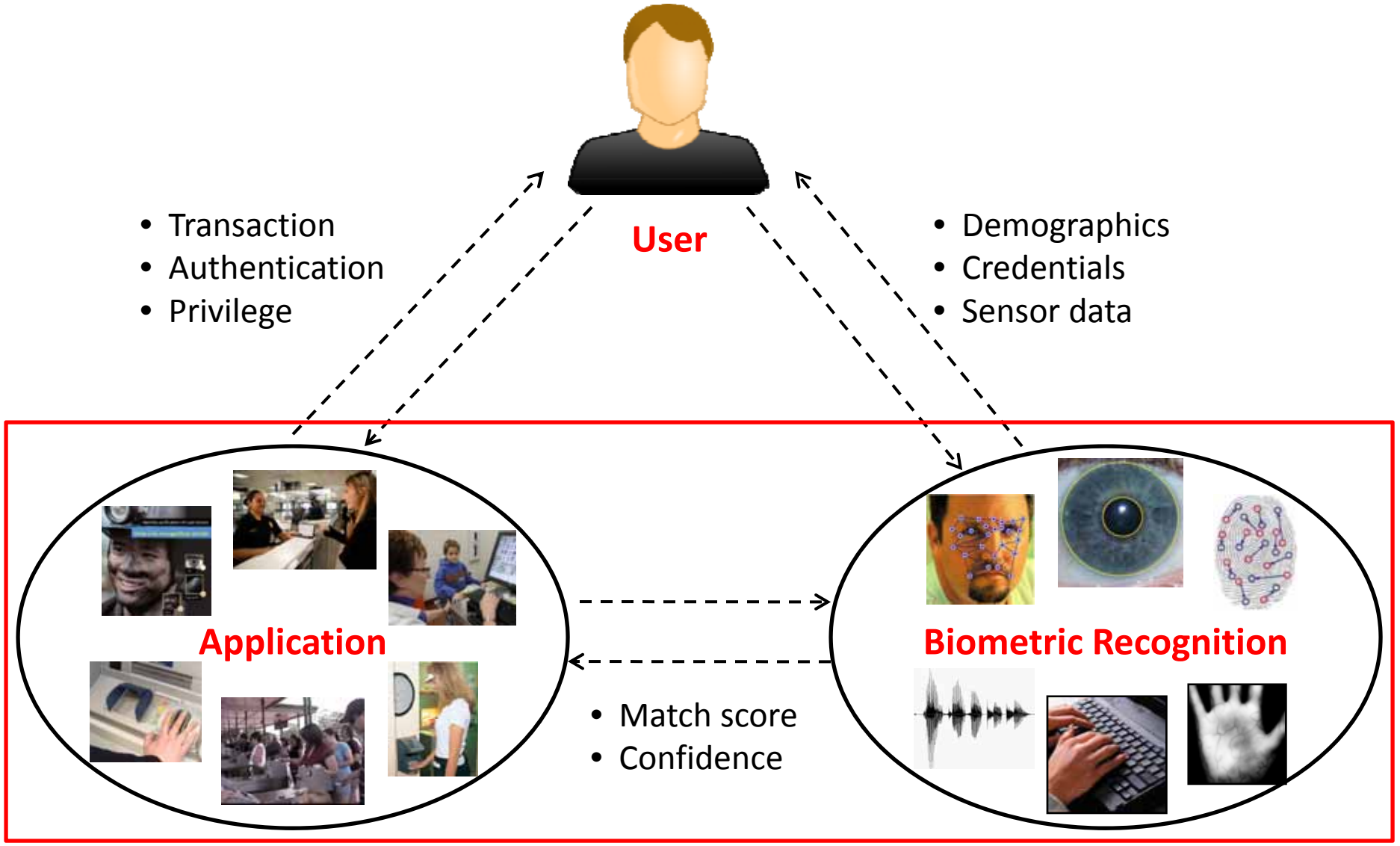


*Identification for Development: The Biometrics Revolution, A. Gelb and J. Clark, Center for Global Development, NW, Washington DC, Working Paper 315, Jan. 2013, http://www.cgdev.org/sites/default/files/1426862_file_Biometric_ID_for_Development.pdf

Objectives & Outline

- What is biometrics?
- How did biometrics get started?
- Where are we now?
- Where do we go from here?

The Biometrics Conundrum

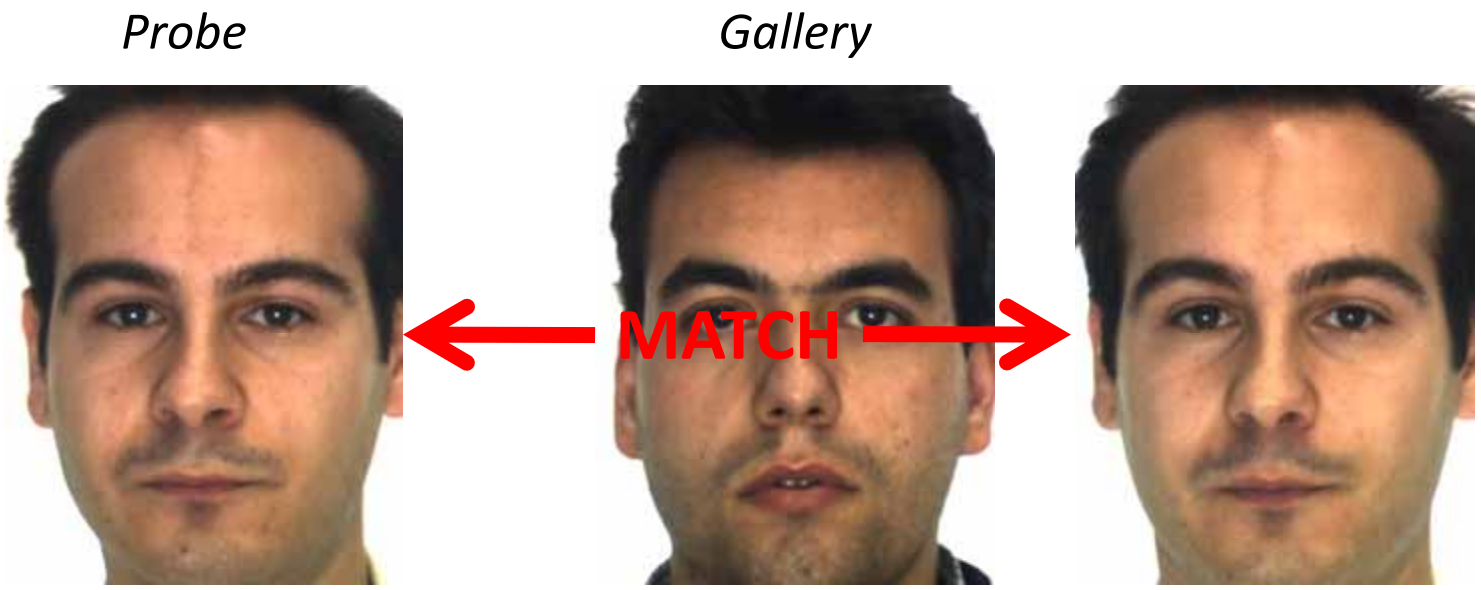


Recognize a person by body traits & link the body to an externally assigned identity

Biometric Challenge

Find a representation & similarity measure such that

- Intra-subject similarity is very high
- Inter-subject similarity is very low



Similarity score > T implies a "match"

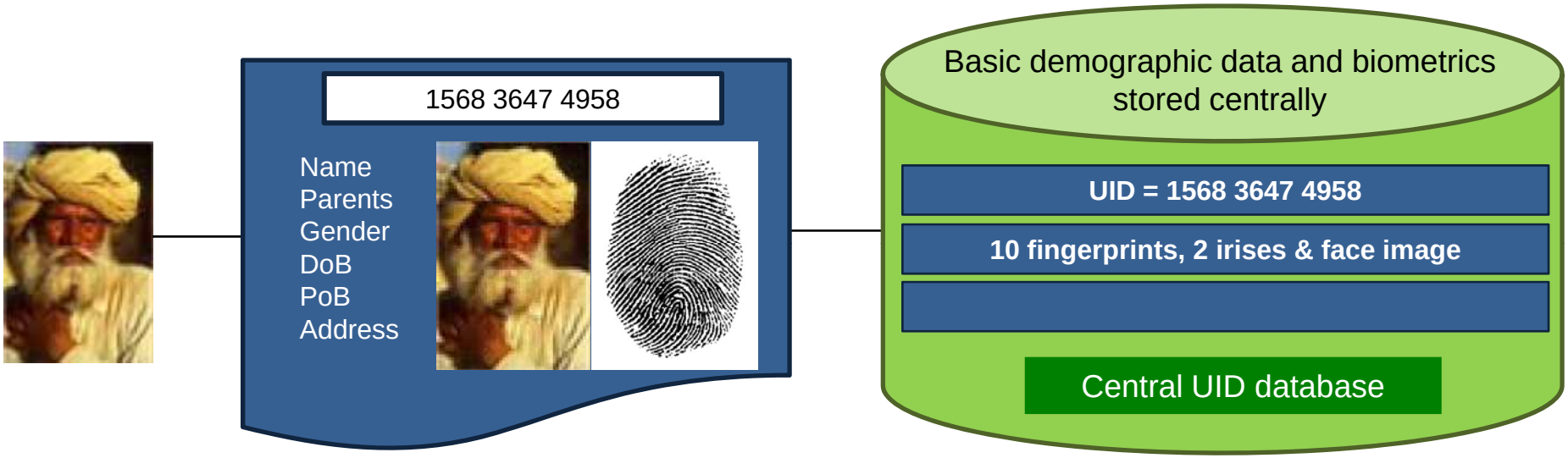
Why Biometrics?

- Security: Does the person have a prior criminal record?
- Convenience: No need to carry credentials (*pw*, *ID*)
- Audit trail: Who accessed the bank vault?
- Fraud: Is the credit card holder the rightful owner?
- De-duplication: One person, one document!

Palm vein scanners used for patient registration in Houston hospital system; 2,488 patients are named Maria Garcia and 231 of them have the same birth date

http://www.usatoday.com/story/news/nation/2012/11/25/palm-scanners-technology-schools/1726175/

India’s Aadhaar Project



“To give the poor an identity”

~350 million unique ID numbers have already been issued

https://portal.uidai.gov.in/uidwebportal/dashboard.do

Applications

Verification

Personalization

Transactions

Healthcare

Convenience

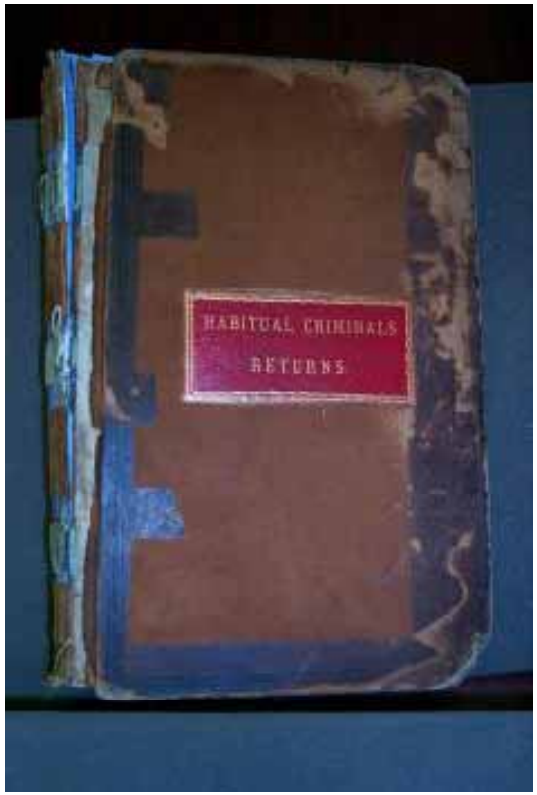
Safety

Travel

Historical Perspective

Habitual Criminal Act (1869)

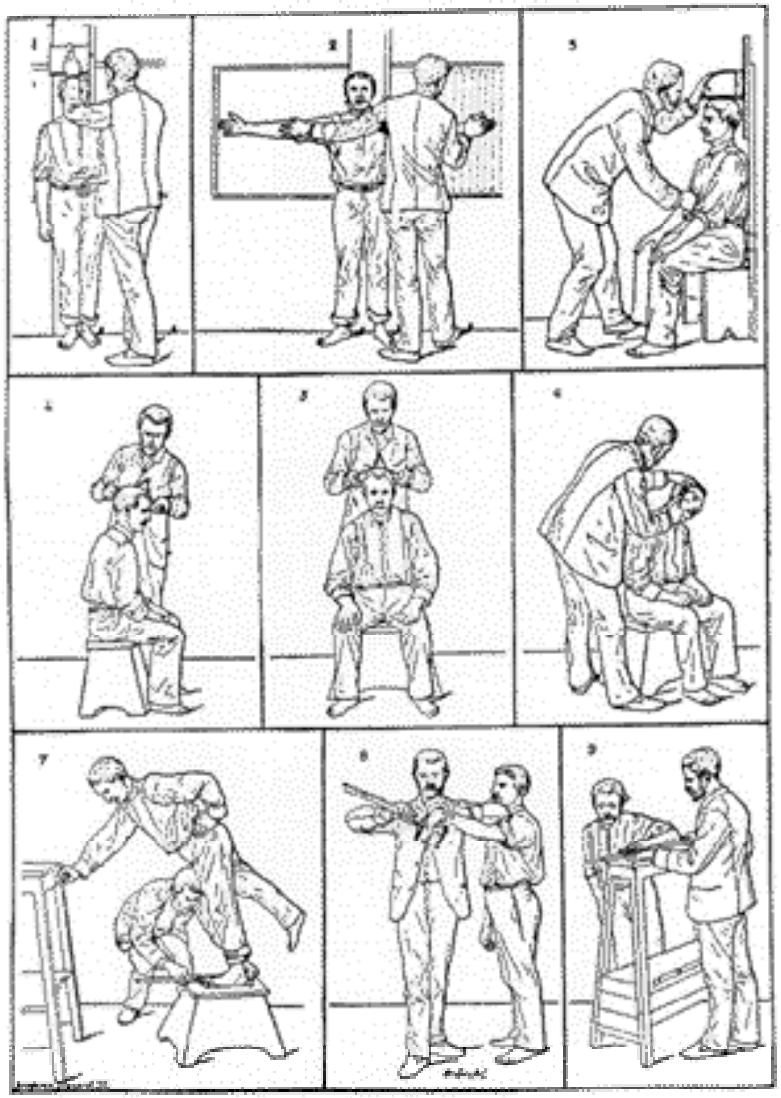
"What is wanted is a means of classifying the records of habitual criminal, such that as soon as the particulars of the personality of any prisoner (whether description, measurements, marks, or photographs) are received, it may be possible to ascertain readily, and with certainty, whether his case is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



Habitual Criminals Returns Book

G. Pavlich, "The Emergence of Habitual Criminals in 19th Century Britain: Implications for Criminology", Journal of Theoretical and Philosophical Criminology, 2(1), pp. 1–59, 2010

Bertillon System (1882)



First use of soft biometrics and multi-biometrics

H.T. F. Rhodes, Alphonse Bertillon: Father of Scientific Detection, Harrap, 1956

Friction Ridge Pattern

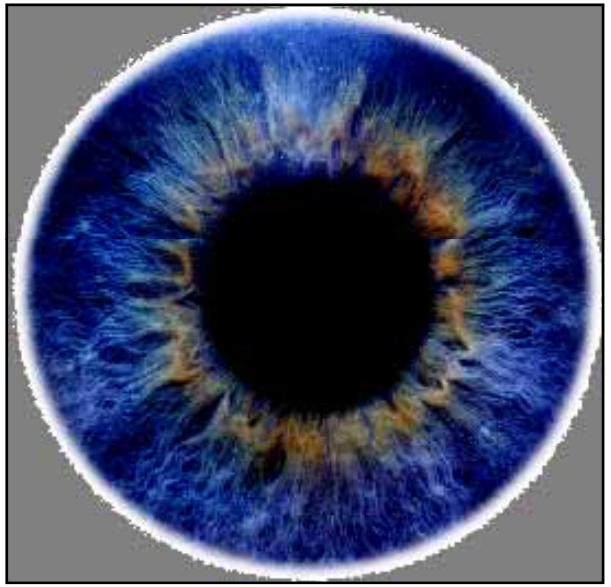
"Perhaps the most beautiful and characteristic of all superficial marks (on human body) are the small furrows with the intervening ridges and their pores that are disposed in a singularly complex yet even order on the under surfaces of the hands and feet."

Francis Galton, Nature, June 28, 1888

Three Most Popular Biometric Traits

- Legacy database
- 1:N search
- NIST evaluation

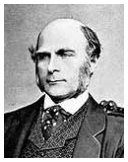
- Legacy database
- Covert capture
- NIST evaluation



- 1: N search
- High accuracy
- NIST evaluation

Fingerprint Recognition Milestones

1880
Henry Faulds
Article on fingerprints published in Nature



1901
Scotland Yard
Adopted Galton/Henry system of classification

1963
Mitchell Trauring
First paper on automatic fingerprint matching

2004
DHS
US-VISIT

2009
UIDAI
India started issuing 12-digit UID no. to its residents

AD 600
China
Fingerprint to seal contracts and legal documents

1893
Argentina
First use of fingerprint as forensic evidence

1924
FBI
Set up fingerprint identification division

1970s
FBI
Initiation of AFIS

2008
FBI
NGI

~1000-2000 B.C.
Ancient Babylon
Finger mark on clay seal

1892
Juan Vucetich
Rolled ink on paper

1990s
Live-scan technique
- Optical sensor
- Solid-state sensor
- Ultrasound sensor

2003
US-VISIT

1997
Thomson-CSF
Swipe sensor

~1995

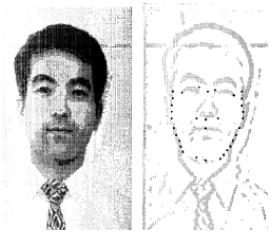
Siemens ID mouse

2005
TBS
Touchless 3D sensor

http://www.alaskafingerprinting.com/Fingerprinting.html
http://commons.wikimedia.org/wiki/File:US-VISIT_(CBP).jpg
http://www.biometricdirect.net/upek-eikon-touch-fingerprint-reader-eikon-touch-700.html
http://www.thehindu.com/news/national/uidai-to-start-informing-aadhar-numbers-through-emails-smses/article2624078.ece
http://www.idex.no/technology/swipe-sensor/
http://www.techneology.org/2009/10/touchless-3-d-fingerprinting.html

Face Recognition Milestones

1964
Woodrow Bledsoe
Face recognition

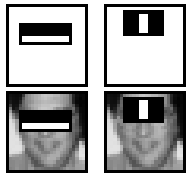


1973
Takeo Kanade
First FR thesis

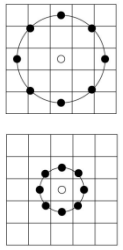
1991
Turk & Pentland
Eigenface

1997
Belhumeur et al.
Fisherface

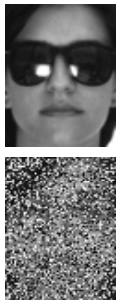
1999
Blanz & Vetter
Morphable face



2001
Viola & Jones
Face detector



2006
Ahonen et al.
LBP



2009
Wright et al.
Sparse rep.

1915
35mm still camera

1991
Kodak
Digital camera
1024p

1990s
Surveillance camera
480p @ 30fps

2000
Sharp
First camera phone
320p

2010-2013
Wearable camera
480P @ 30fps
Google Glass
720p @30fps

April 2013
Samsung Galaxy S4
1080p @ 30fps

Bledsoe, W. W. 1964. The Model Method in Facial Recognition, TR PRI 15, Panoramic Research, Inc., California.
Takeo Kanade, Picture Processing System by Computer Complex and Recognition of Human Faces, Kyoto Univ.,1973.
M. Turk and A. Pentland, Eigenfaces for recognition. Journal of Cognitive Neuroscience 3 (1): 71–86, 1991.
Belhumeur, P.N. et al., Eigenfaces vs. Fisherfaces: recognition using class specific linear projection, PAMI, 19-7, 1997.
V. Blanz and T. Vetter, A morphable model for the synthesis of 3D faces, SIGGRAPH 1999.
http://commons.wikimedia.org/wiki/File:Three_Surveillance_cameras.jpg
http://photodoto.com/camera-history-timeline/
Viola, Jones: Robust Real-time Object Detection, IJCV 2001.
Ahonen,et al. Face Description with Local Binary Patterns: Application to Face Recognition, *PAMI,* 2006.
J. Wright et al. Robust Face Recognition via Sparse Representation, PAMI, 31-2, 2009.
http://static7.businessinsider.com/image/4d013ea7cadcbb7033010000/looxcie-video-camera.jpg
http://www.techinasia.com/samsung-galaxy-s4-infographic/

Iris Recognition Milestones

1936
Frank Burch
Concept of using iris patterns for human identification

1985
Flom and Safir
First iris recognition patent

1989
John Daugman
First iris camera

1991
John Daugman
Iris recognition patent

1995
IrisScanner System
One of the earliest commercial iris cameras

2001
UAE
Deployed iris recognition system for border control

2002
USA
Use of iris recognition in field operations

2004
SecuriMetrics
Portable iris recognition device

2005
Flom and Safir
Patent expired

2006
Sarnoff
Iris on the Move

2009
UIDAI
National ID

2010
Mexico
National ID

2011
John Daugman
Patent expired

2011
Indonesia
National ID

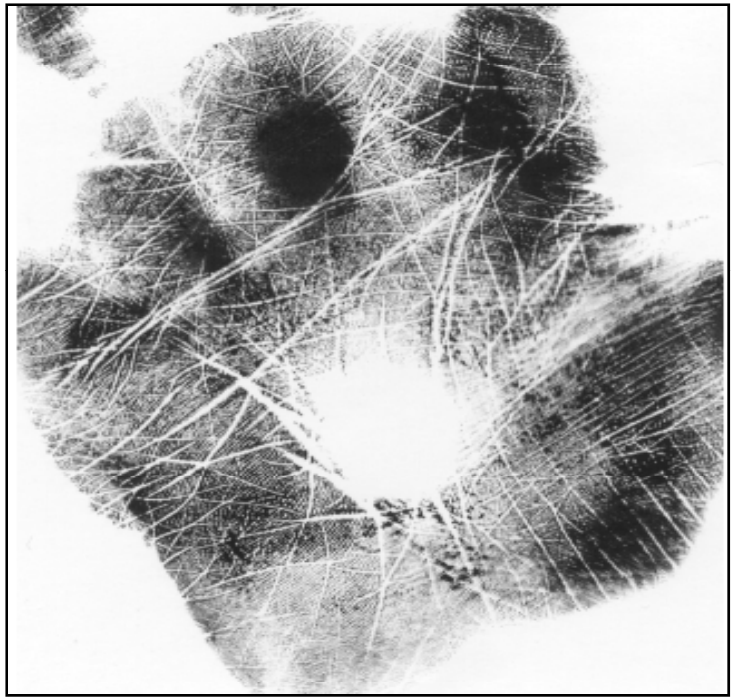
2013
AOptix
App & device for smartphone to capture iris

2013
DeltaEye

https://www.fbo.gov/index?s=opportunity&mode=form&tab=core&id=1d31acd78d7a20b1fe598bf4b4661d6b
http://www.sri.com/engage/products-solutions/iom-passport-portal-system
http://www.cnn.com/2013/04/16/tech/mobile/mashable-biometric-iphone-scanner

Other Biometric Traits

Traits with Legacy Database

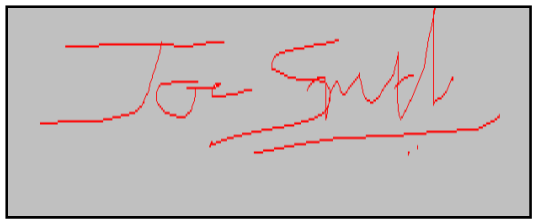


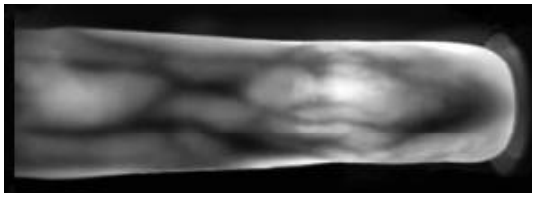
- ~30% of latents are of palmprints
- FBI's NGI will have latent palmprint matching capability

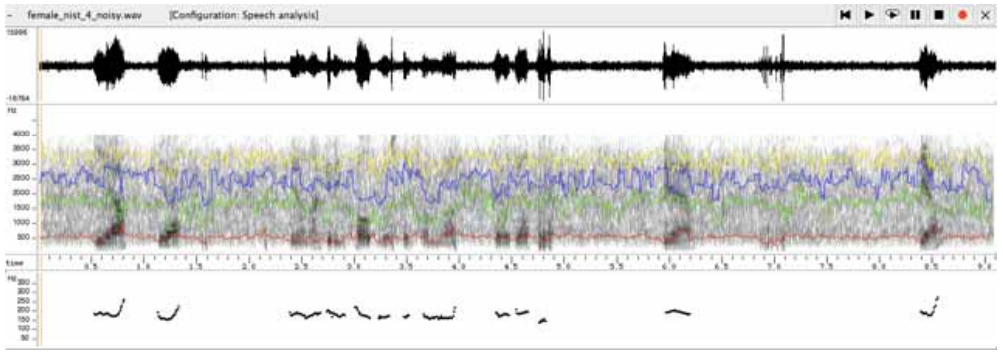
- Trace evidence
- Innocence project
- Real-time DNA matching

Capability to conduct 1:N search

Traits in Commercial Systems

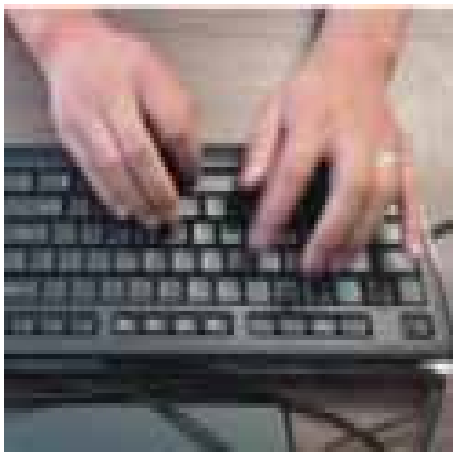






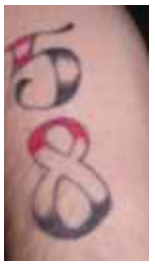
Primarily for 1:1 match

Traits in Laboratory Stage







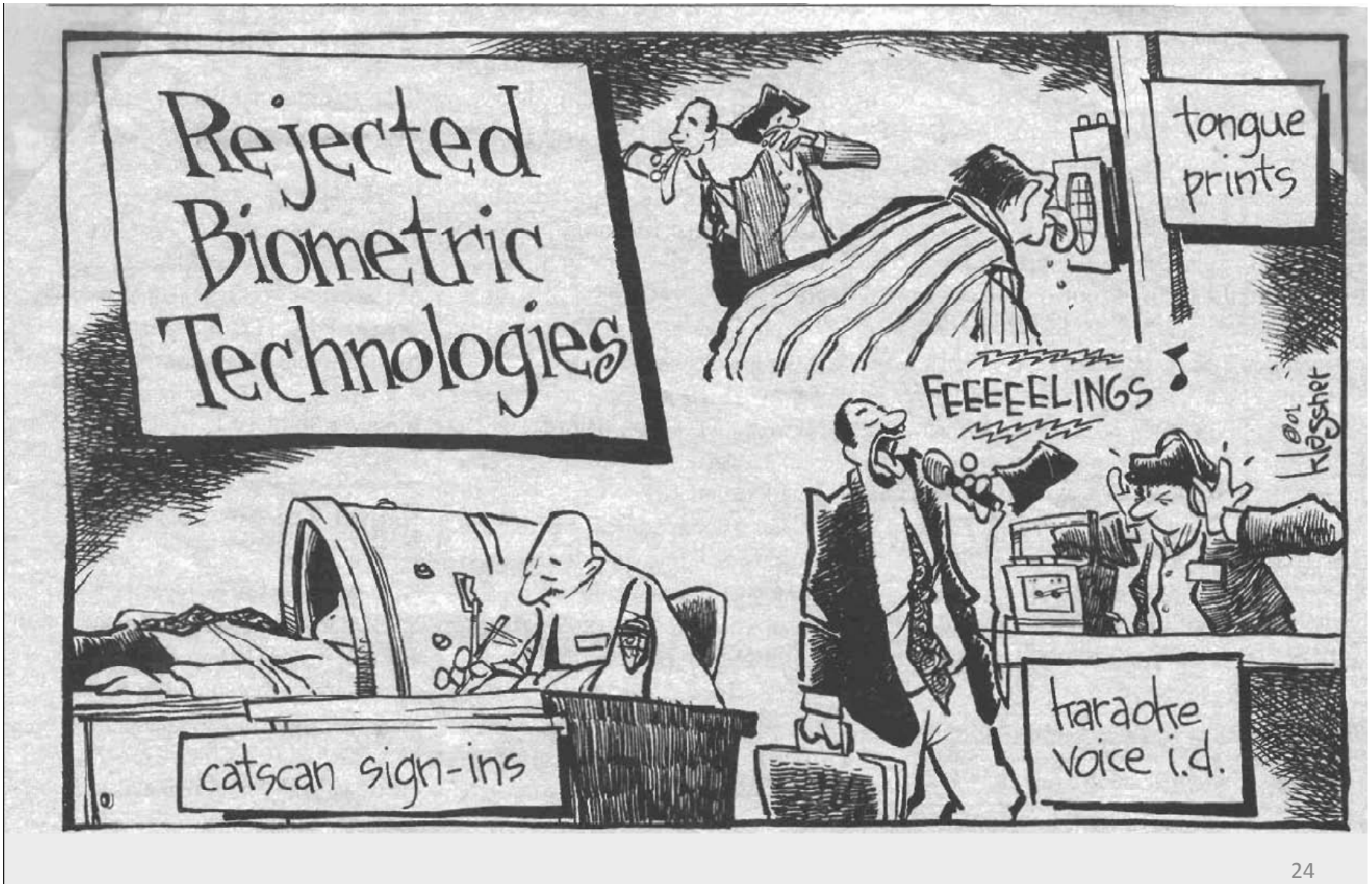
Which Biometric Trait?

Requirements of a Biometric Trait

- **Uniqueness** (Is it distinctive across users?)
- **Permanence** (Does it change over time?)
- **Universality** (Does every user have it?)
- **Collectability** (Can it be measured quantitatively?)
- **Performance** (Does it meet error rate, throughput..?)
- **User experience** (Is it acceptable to the users?)
- **Vulnerability** (Can it be easily spoofed?)
- **Integration** (Can it be embedded in the application?)

No biometric trait is “optimal”, but many are “admissible”

Rejected Biometric Traits



Where is Biometrics Now?

Fingerprint Matching

- Plain-to-plain matching
  - NIST FpVTE (2003): 99.4% TAR at 0.01% FAR
- Latent-to-rolled matching
  - NIST ELFT-EFS II (2012): 63.4% rank-1 accuracy
  - On NIST SD27, state-of-the-art rank-1 accuracy: ~72%

NIST FpVTE

NIST ELFT-EFS

Matching speed: ~millions/sec for tenprint matching on a single server

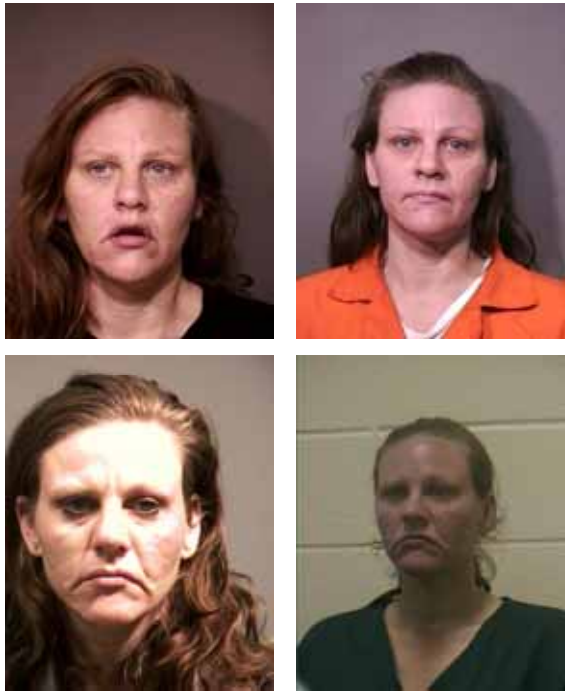
C. Wilson *et al.*, Fingerprint Vendor Technology Evaluation 2003: Summary of Results and Analysis Report, NISTIR 7123, 2004
M. Indovina *et al.*, Evaluation of Latent Fingerprint Technologies: Extended Feature Sets [Evaluation #2], NISTIR 7859, 2012

Face Recognition

FRVT 2012	TAR @ FAR = 0.1%
Mugshots	**96%**
Visa photos	**99%**

Search Time (640k gallery faces): **0.3 seconds**

http://www.nist.gov/itl/iad/ig/frvt-2012.cfm



http://www.nist.gov/itl/iad/ig/sd32.cfm

MEDS-II	TAR @ FAR = 0.1%
Eigenfaces	**9%**
Fisherfaces	**35%**
LBP	**34%**
COTS-A	**58%**
COTS-B	**88%**
COTS-C	**97%**

Iris Recognition

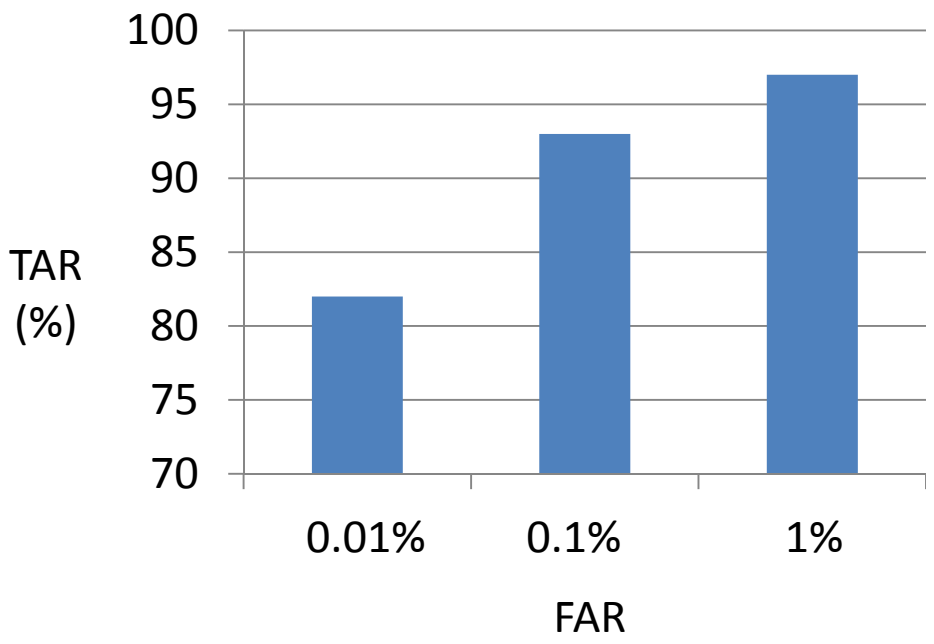
- Iris images collected from 4.3 million eyes (6.1 M images)
- Over the 95 algorithms evaluated, single-eye iris false negative identification rates (i.e. “miss” rates) are at 1.5% or higher. For two eyes, FNR = 0.7%
- No. of false positives is 25 out of a total of 10^{13} comparisons
- Pupil dilation & constriction can impact iris recognition
- Template size varies between 1KB and 20KB

http://www.nist.gov/itl/iad/ig/irexiii.cfm

Speaker Recognition

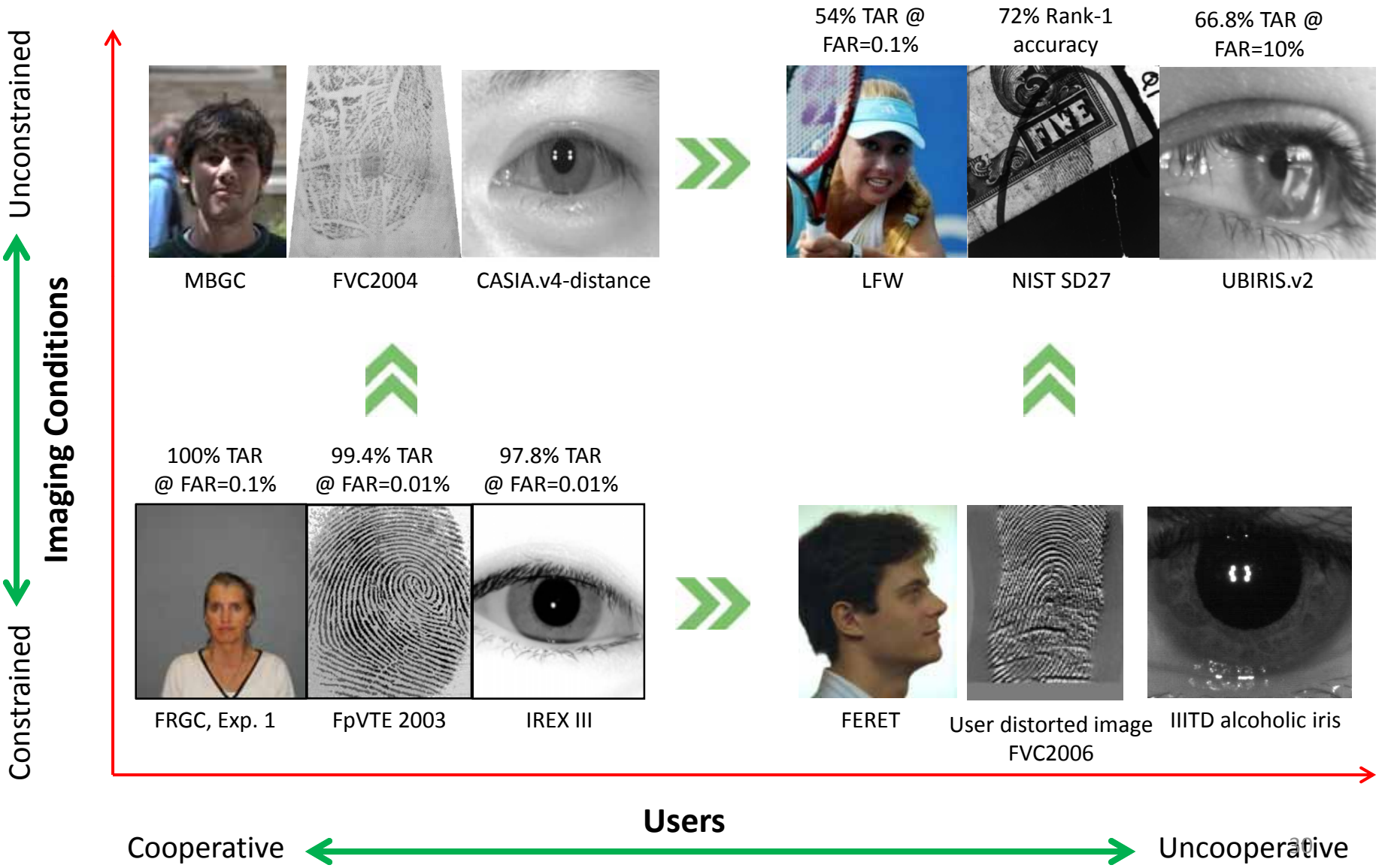
- Given a target speaker and a test speech segment, is the target speaking in the test segment?
  - A trial consists of: Target Speaker ID + Test segment

NIST SRE12	
Systems tested	75
Test Segment Duration	30-300s
Number of Trials Target Speakers Known Non-Target Unknown Non-Target	~2million 2,897 46,601 61,871



C. Greenberg *et al*., The 2012 NIST Speaker Recognition Evaluation, NIST SRE12, December 11-12 2012, Orlando, Florida
http://www.nist.gov/itl/iad/mig/sre12results.cfm

From Solved to Unsolved

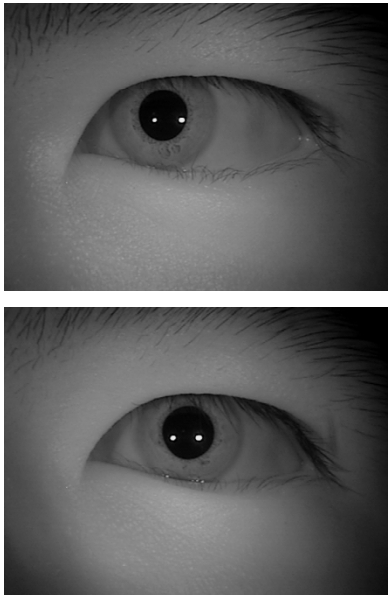


Unsolved Problems

- Fundamental problems
  - Uniqueness (individuality)
  - Permanence (persistence)
- Application-driven problems
  - Unconstrained sensing environment (surveillance)
  - System security & user privacy
    - Template security
    - Anti-spoofing

Uniqueness

- Given a 10-digit PIN, no. of unique identities that can be resolved = 10 billion
- But, what can we say about a biometric trait?
- How many traits to identify 7 billion individuals?
- Body trait vs. sensed image



No. of monozygotic twin birth rate is about three in every 1,000 births worldwide

Persistence

- Human body (hence biometric traits) will age over time
- Can we devise an age-invariant template?

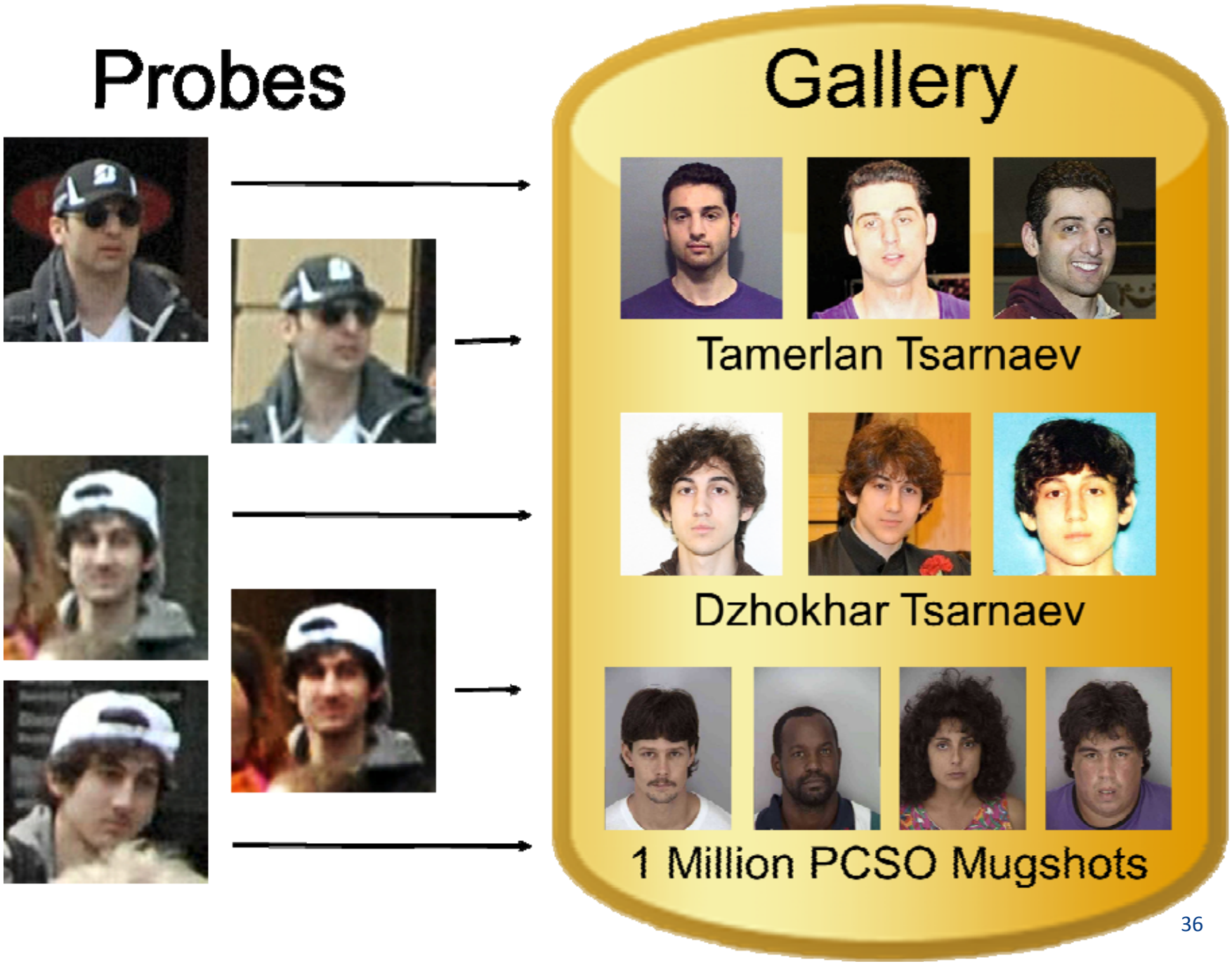
Images from PCSO mugshot database; Courtesy Scott McCallum

Cameras Everywhere

1M CCTV cameras in London & 4M in U.K.; average Briton is seen by 300 cameras/day; 400K cameras in Beijing provide 100% coverage of public places; 150K cameras in Seoul

Face Recognition in Video

How to detect “persons of interest in a video” and then identify them?


Probes
Gallery
Tamerlan Tsarnaev
Dzhokhar Tsarnaev
1 Million PCSO Mugshots

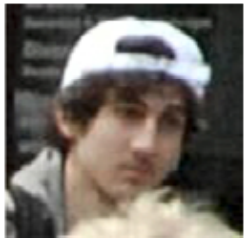
Top Retrieval Ranks for Tsarnaev Brothers

(with demographic filtering)

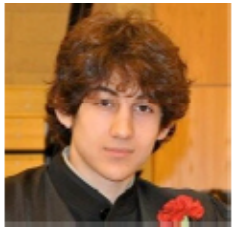
116,342

12,446

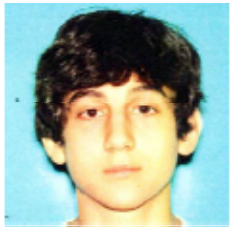
87,501



1,869

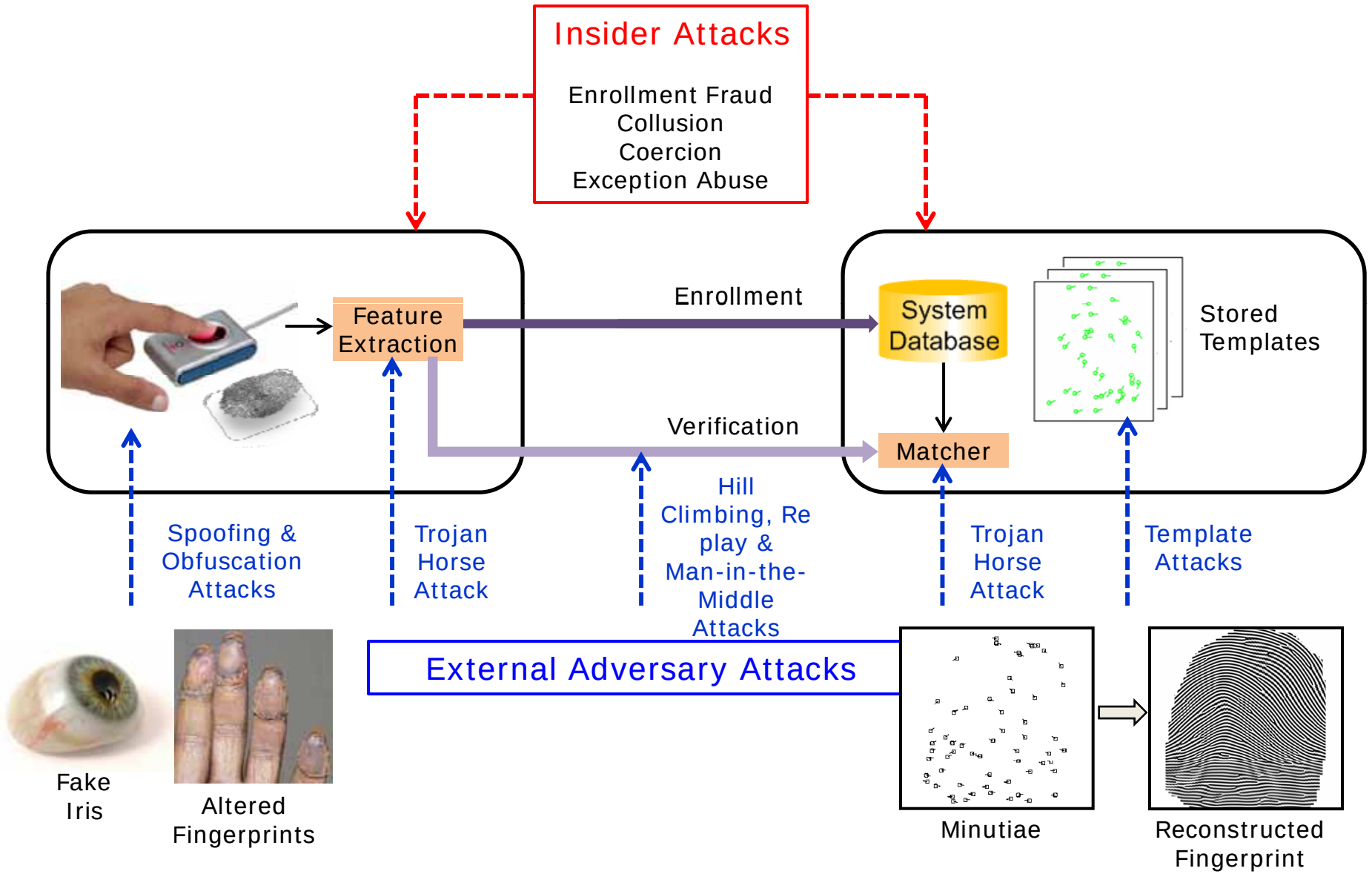


1

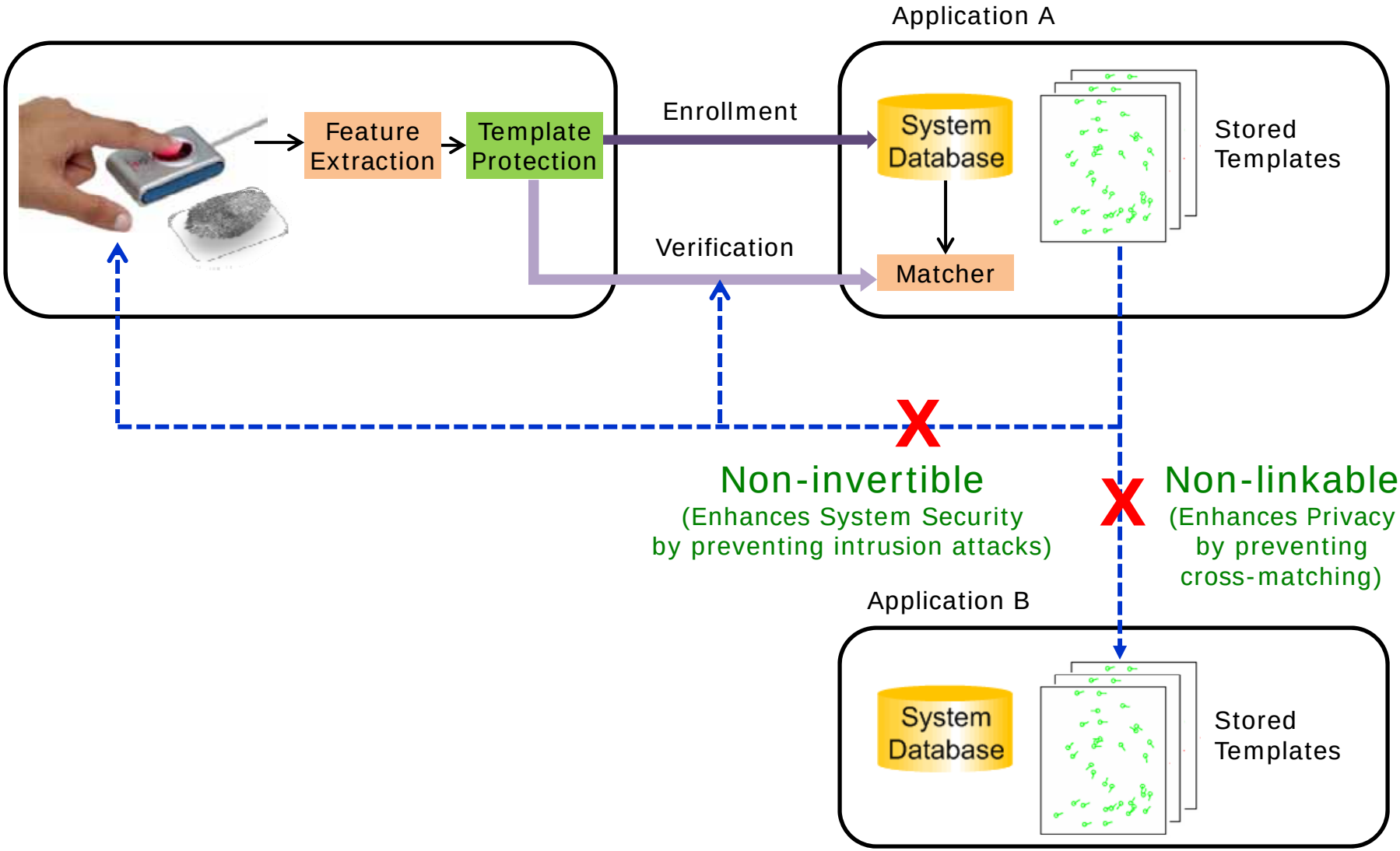


12,622

Biometric System Vulnerabilities



Biometric Template Protection



Can we generate a non-invertible AND non-linkable biometric template without compromising the matching accuracy?

Biometric Key Generation

Courtesy: Prof. Tyfun Agkul, Istanbul Technical University

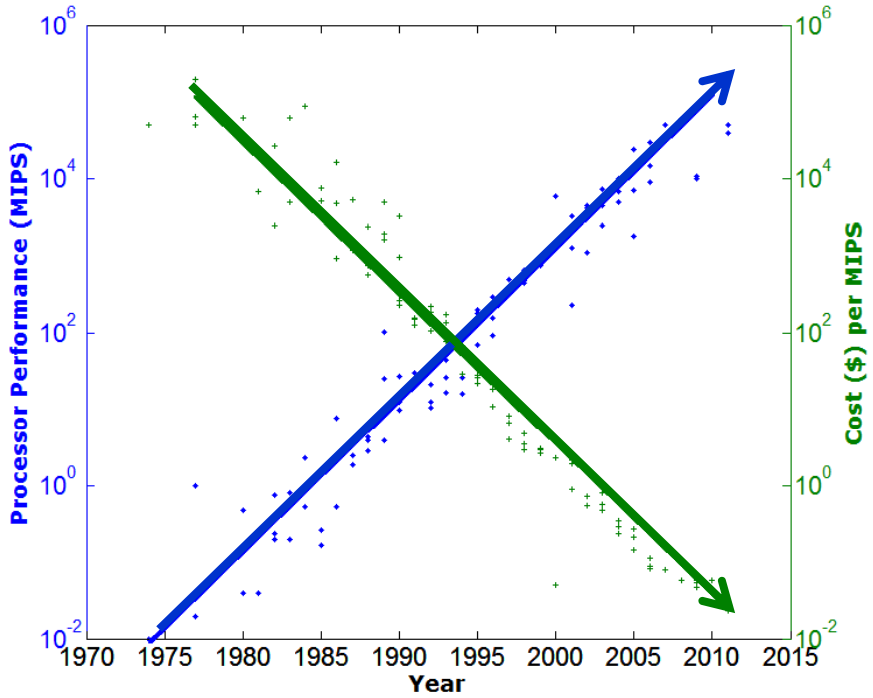
Circumvention

Face Liveness

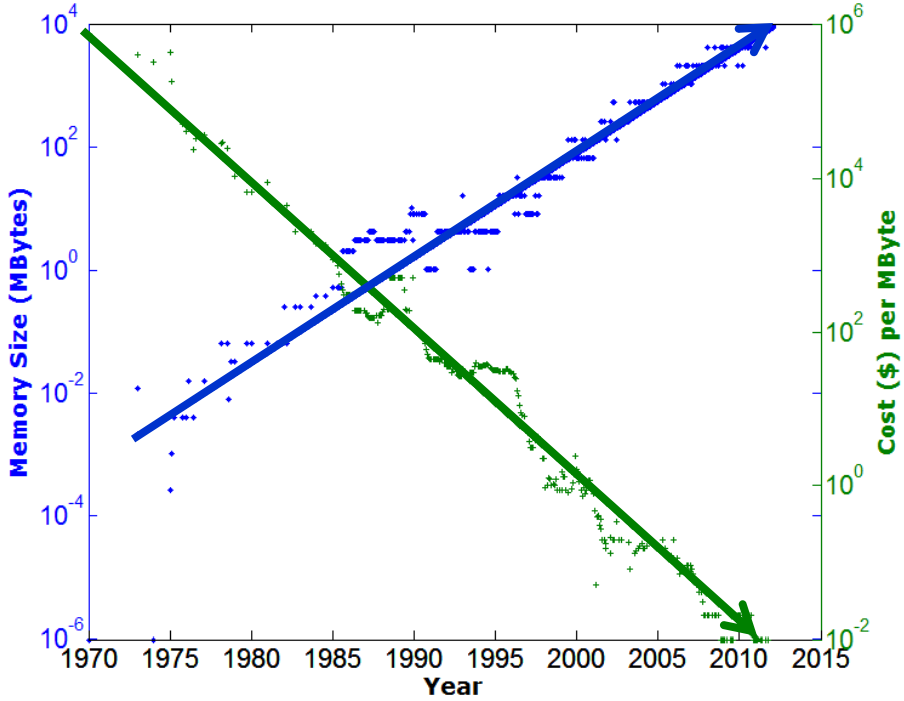
Where is Biometrics Going?

- Processor, memory & sensors
- Ubiquitous biometrics
  - Context
  - Privacy
- Biometrics for societal good
- Personalization
- Biometrics & forensics

Processor, Memory and Sensing Technology



Microprocessor performance vs. cost



RAM capacity vs. cost

1892
Ink and paper

1990s
Optical sensor

1990s
Capacitive sensor

1997
First swipe sensor

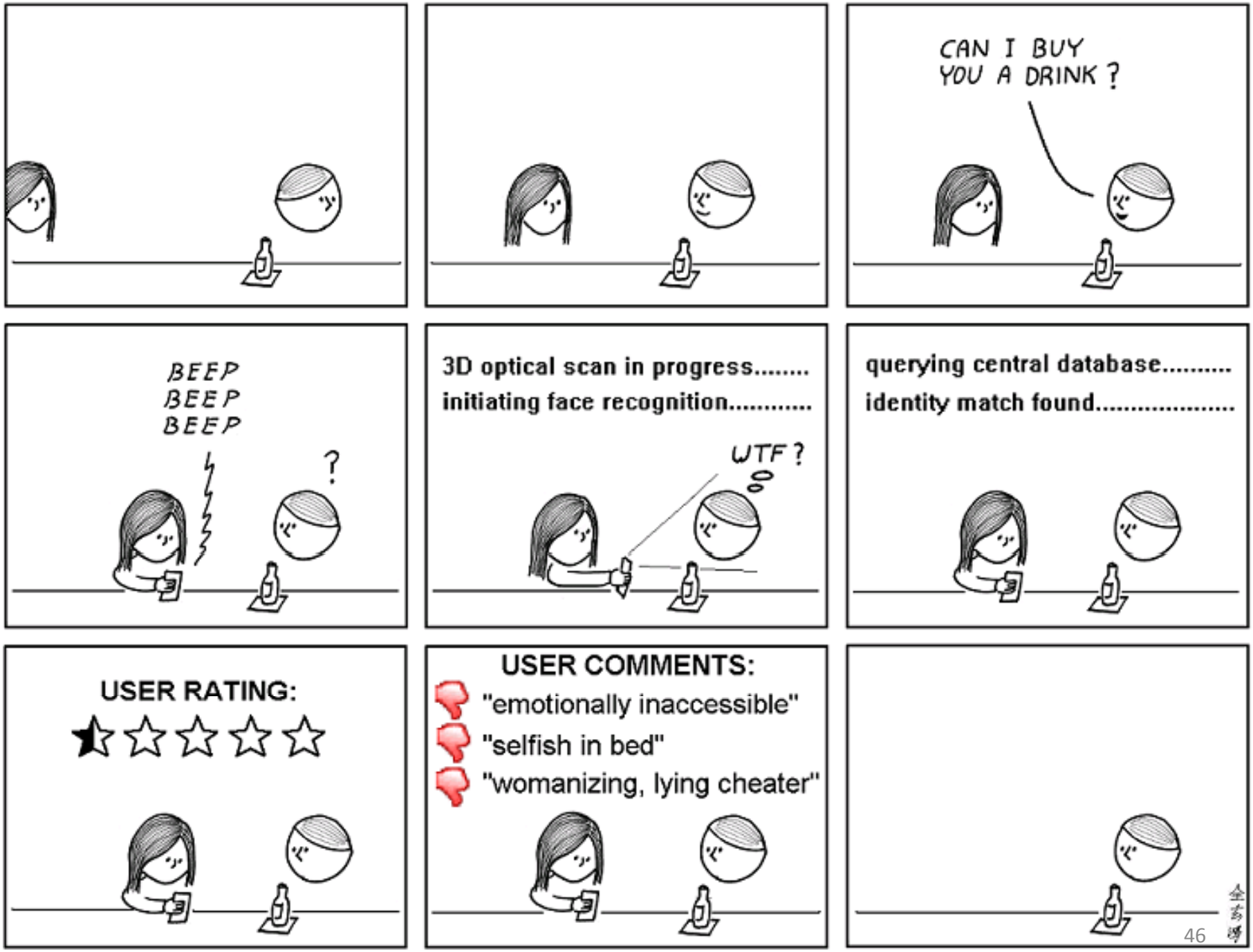
2007 US-VISIT
Slap sensor

2010 SAFRAN
Touchless swipe sensor

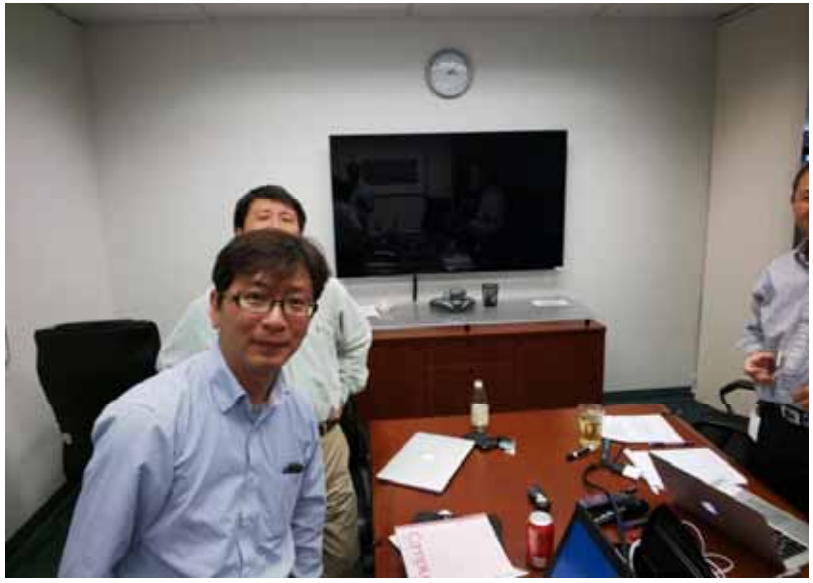
Ubiquitous Biometrics

Biometrics will become more holistic, where location, behavior and recent interaction history fuse with multimodal biometric ID (strong and weak traits) to provide a strong assurance of identity. This degree of integration is both inevitable and necessary for ubiquitous biometrics.

Courtesy Rob Rowe, Lumidigm


CAN I BUY YOU A DRINK ?
BEEP BEEP BEEP
?
3D optical scan in progress.....
initiating face recognition.....
WTF ?
querying central database.....
identity match found.....
USER RATING:
USER COMMENTS:
"emotionally inaccessible"
"selfish in bed"
"womanizing, lying cheater"

Google Glasses

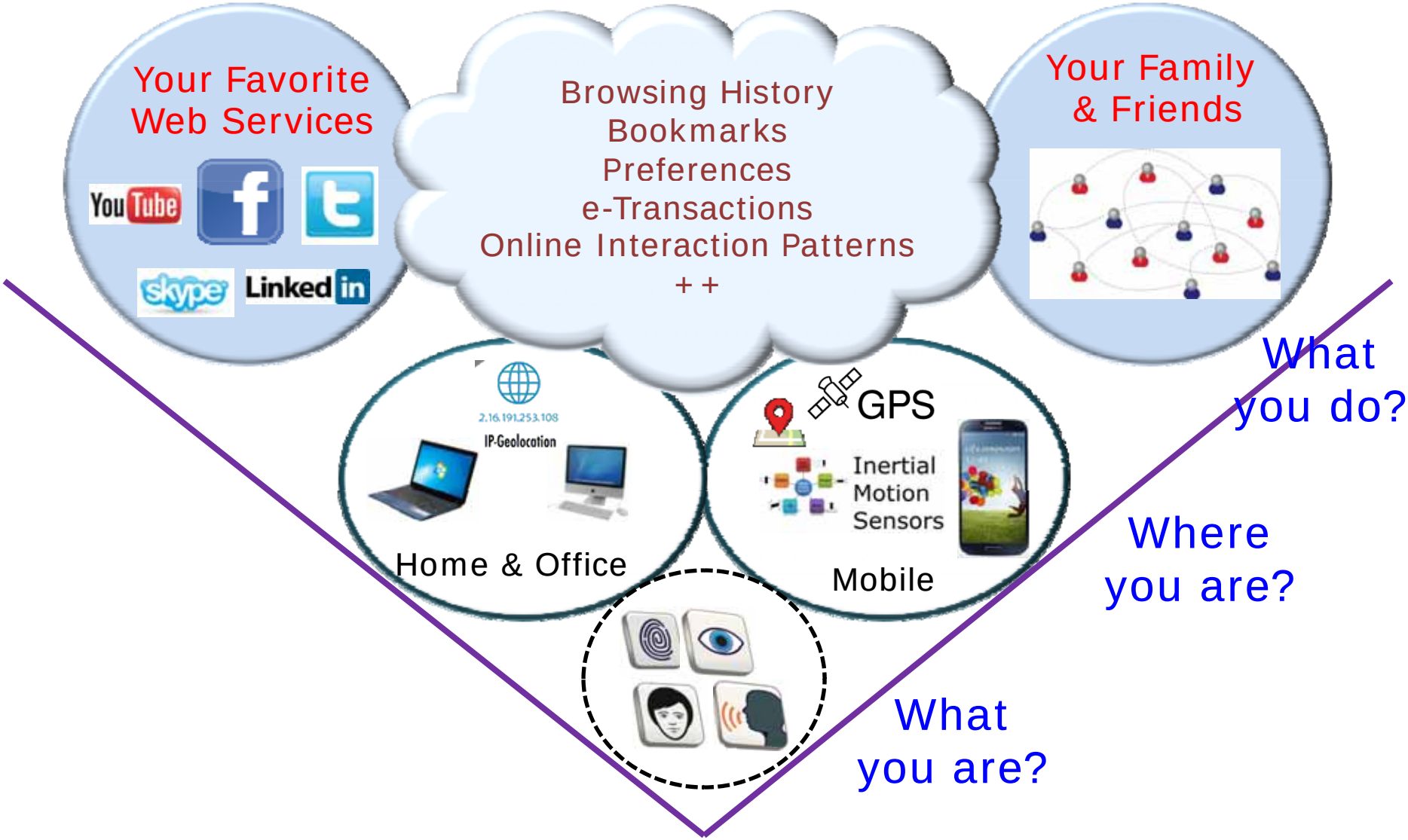


Privacy

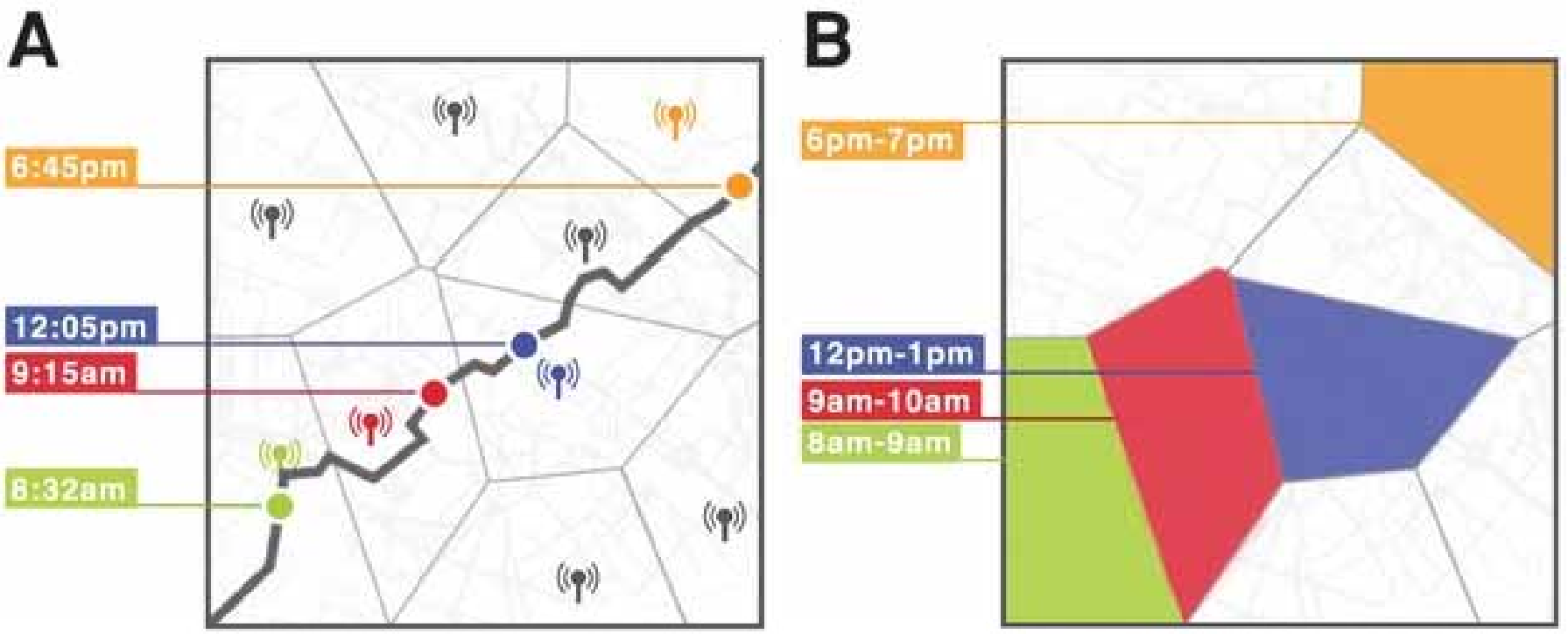
"Cafes ban Google glasses to protect customers' privacy: Fears users of futuristic eyewear can record without permission."

http://www.dailymail.co.uk/sciencetech/article-2323578/Cafes-ban-Google-glasses-protect-customers-privacy-Fears-users-futuristic-eyewear-record-permission.html#ixzz2UgEfuN8F

Your Digital Footprint Defines You



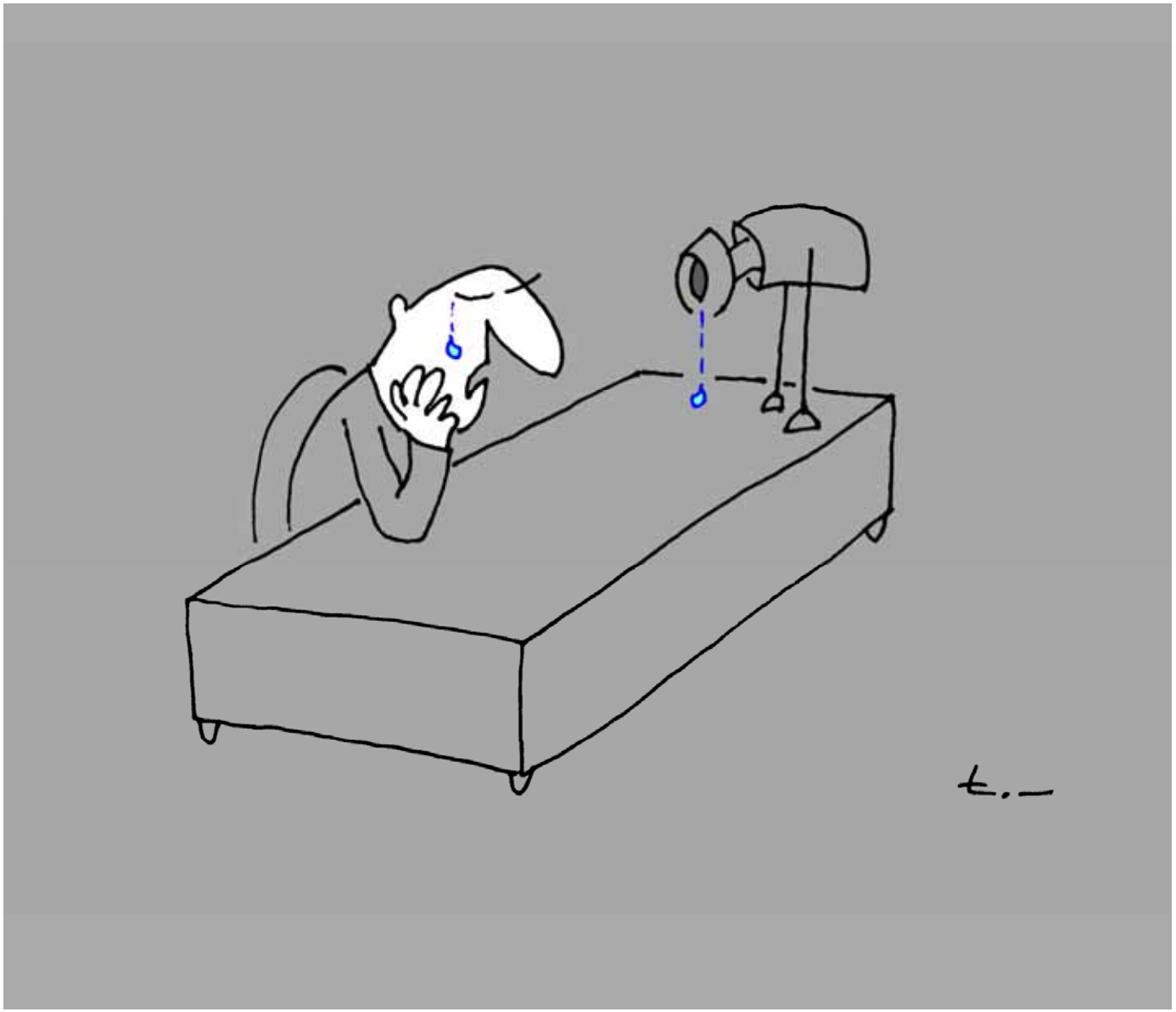
GPS Fingerprint:
Identification Without Biometric Data



With just the anonymous location data, one can figure out "who you are" by tracking your smartphone. Patterns of our movements, when traced on a map, create something akin to a fingerprint, unique to every person.

De Montjoye, Hidalgo, Verleysen & Blondel, "Unique in the Crowd: The Privacy Bounds of Human Mobility", Scientific Reports, vol. 3, 2013

Affective Biometrics



Courtesy Prof. Tayfun Akgul, ITU

Cell Phone Science

(By Bill Gates, Nov 09, 2010)

"Most of us think of cell phones primarily as a convenient tool to stay in touch with people and store information. But increasingly, scientists are exploring ways to use cell phones to deliver critical health care to people in developing countries."

Over 1.7 billion mobile phones were sold worldwide in 2012 alone

http://www.gartner.com/newsroom/id/2335616
http://www.thegatesnotes.com/Topics/Health/Cell-Phone-Science

Mobile Phone-based Vaccination Registry

16 months old boy, right ring finger

Use fingerprint scans to track children who have received immunizations. The goal is to reduce redundant doses and increase coverage levels in developing countries (Mark Thomas, VaxTrak)

http://vaxtrac.com/about

Locard's Exchange Principle

Edmond Locard (1877–1966), a pioneer in forensic science, stated that the perpetrator of a crime will bring something into the crime scene and leave with something from it, and that both can be used as forensic evidence.

"….. Not only his fingerprints or his footprints, but his hair, the fibers from his clothes, the glass he breaks, the tool mark he leaves, the paint he scratches, the blood or semen he deposits or collects. All of these and more, bear mute witness against him. This is evidence that does not forget. …..Only human failure to find it, study and understand it, can diminish its value."

Paul Kirk, *Crime investigation: physical evidence and the police laboratory*. Interscience Publishers, NY 1953

http://en.wikipedia.org/wiki/Locard%27s_exchange_principle

A Brief History of DNA Testing

Matches actual samples rather than templates

Tests results in < 2 hours

Before DNA: Blood Typing — 1916

1953 — Double helix structure of DNA first discovered

1986 — RFLP: The first DNA Fingerprinting

PCR, STRs and the Onset of Modern DNA Testing — 1988

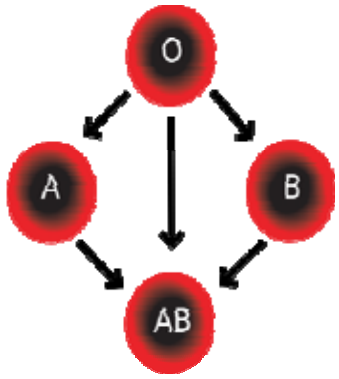
1992 — Y Chromosome Based Tests

Mitochondrial Based Tests — 1996

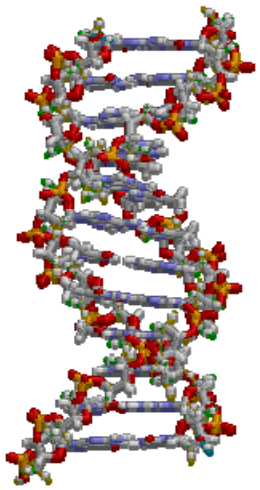
Non-Human DNA Forensics

Rapid DNA — 2010s

Touch DNA



Blood Typing



Double helix structure of DNA

Y Chromosome Tests

Touch DNA

http://www.forensicmag.com/article/touch-dna-crime-scene-crime-laboratory

http://www.newenglandinnocence.org/knowledge-center/resources/dna/

Summary & Conclusions

- Biometrics Recognition is here to stay
- Research vs. Technology
- Drivers for academic researchers:
  - Error rates (but what's the baseline?), new biometric traits, fusion,…
- Drivers for technology providers:
  - Requirements (error rates, template size, processor, throughput), seamless integration, usability, return on investment

My Observations

1. Biometric System: Almost always embedded in an application
2. Biometric Trait: No optimal one, but some are better than others
3. Matcher Accuracy: Zero error is neither required nor guaranteed
4. System Evaluation: Error rates in lab test are lower than field test
5. Baseline: Improper baseline provides false sense of progress
6. Security: Biometrics is an effective tool only if implemented well
7. Biometric Template: Feature extraction is not a one-way function
8. Fusion: Does not guarantee better performance and security
9. Match Score: Gaussian density is not advisable. Tails are critical
10. Impact: Not without a perspective on application & technology

Acknowledgement