

# Challenges of Fingerprint Biometrics for Forensics

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Escuela Politécnica Superior



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4. AFIS: Performance
5. Case Study: AFIS Performance Analysis
6. Conclusions

# Introduction: The scenario in Fingerprint Forensics

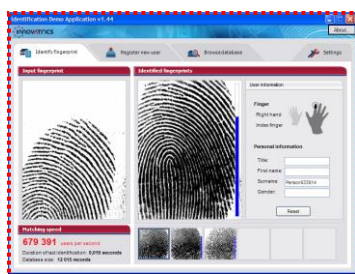


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## Applications of Fingerprint Recognition

### Fingerprint Recognition:

- ✓ Security
- ✓ Access Control
- ✓ Person Authentication
- ✓ Forensic Intelligence



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## Information Levels in Fingerprints

- **Level 1:** General ridge pattern



Arch



Whorl



Right Loop

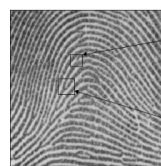


Left Loop

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## Information Levels in Fingerprints

- **Level 2:** minutiae
  - Ridge bifurcation
  - Ridge termination



Terminación de Cresta



Bifurcación de Cresta

- **Level 3:** pores, incipient ridges

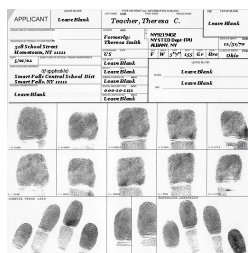


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## Fingerprint Impressions

The acquisition process is controlled by an expert.

- **Rolled Impressions:** larger size and higher number of minutiae.
- **Plain Impressions:** less distorted and clearer ridges.
- **Ten-print cards:** Contain plain and rolled impressions of the ten fingers of a person.



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## Latent Fingerprints

Unknown fingerprints that are found in crime scenes

- Incomplete
- Distorted
- With artifacts



Identification  
becomes  
difficult



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## Manual Fingerprint Comparison



- A = Analysis = Validity & Quality
- C = Comparison = Mark & Compare 3 Levels
- E = Evaluation = Identification/Exclusion/Inconclusive
- V = Verification = Independent re-examination

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## Fingerprint Reporting

- Based in its high discrimination power, three possible states for reporting:
  - *Identification: detection of more than N minutiae (N~12-16)*
  - *Exclusion: clear differences*
  - *Inconclusive: detection of less than N minutiae*

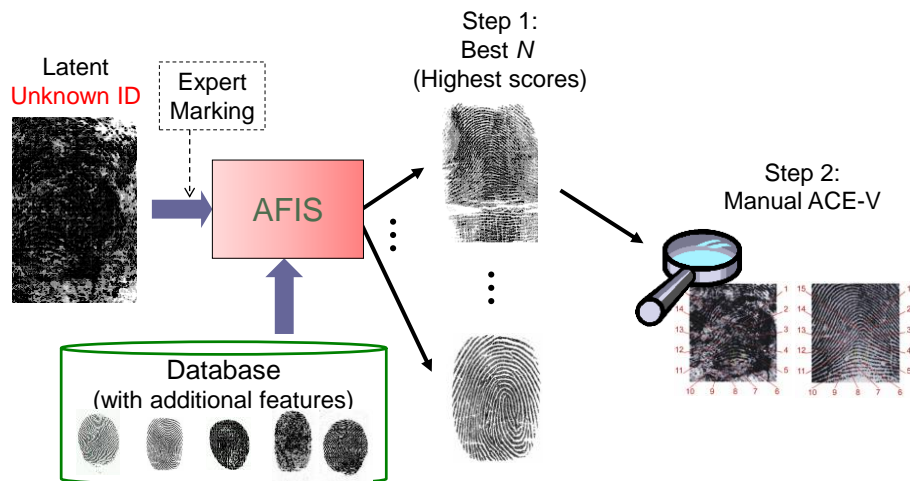
For decades considered “the golden standard of forensic identification”

- Fingerprint experts have long claimed:
  - “Absolute certainty of identifications and zero error rate”
  - “Probable, possible, or likely identification are outside the acceptable limits of the science of friction ridge identification”, (SWG-FAST 2002)

**SWGFAST** Scientific Working Group on Friction Ridge Analysis, Study and Technology

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## Automated Fingerprint ID Systems



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## AFIS: Feature Extraction (I)



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## AFIS: Feature Extraction (II)

- Extended Features:
  - Singularities, Q map, texture, orientation, ridges, dots and incipients, ...

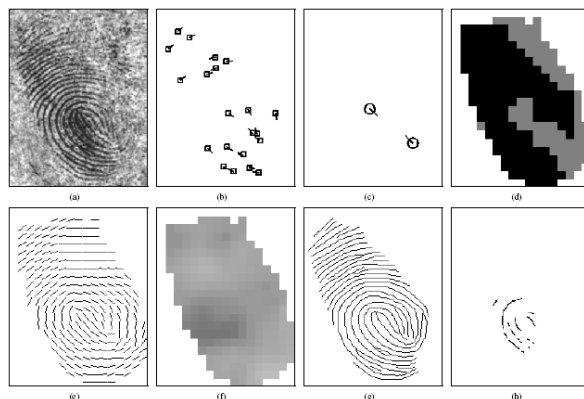


Fig. 2. Features in a latent fingerprint. (a) Grayscale image, (b) minutiae, (c) singular points (cores), (d) ridge quality map (darkness indicates high quality level), (e) ridge flow map, (f) ridge wavelength map, (g) skeletonized image, (h) dots and incipient ridges.

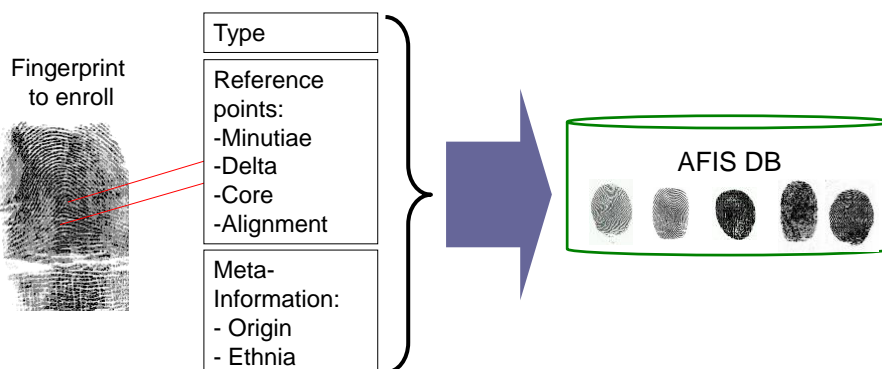
A. K. Jain, J. Feng,  
"Latent Fingerprint  
Matching", *IEEE Trans.  
on PAMI*, 2010.

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## AFIS Databases

- Additional information provided by the expert when enrolling
  - (Semi-)Automatic Feature Extraction
  - Additional Information provided by the expert when enrolling



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## Forensics: Art or Science?



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## Forensic Identification

- Forensic Identification Science deals with *identification of the source*
  - Based in highly discriminant features, some “classical” techniques as:
    - Fingerprints
    - Toolmarks
    - Shoemarks
    - Firearms
- have a long tradition reporting “*identification*” conclusions

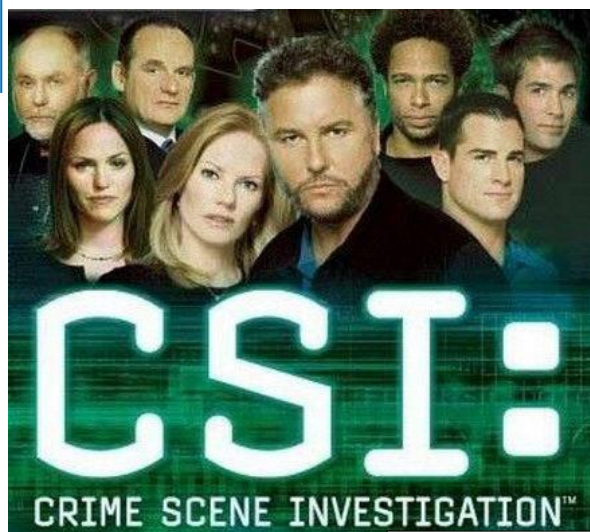
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## The concept of "Identification"

- In Biometrics (e.g. Fingerprint Recognition) we are used to identification error rates  
identification decisions  $\leftrightarrow$  errors
- In criminalistics, an *identification* means that the source can be individualized from any other possible source in the world (*discernible uniqueness*)  
 $\Rightarrow$  absolute conclusion, no place for errors
- An "*identification*" conclusion will be interpreted as an expression of the criminal standard "*beyond reasonable doubt*"

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CSI is to Forensic Science what  
Science Fiction is to Science

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**CSI and its Effects: Media, Juries, and the Burden of Proof**  
Simon A. Cole  
University of California, Irvine - Department of Criminology, Law and Society

**The CSI Effect: Popular Fiction About Forensic Science Affects Public Expectations About Real Forensic Science**  
H.J. Schmitzler  
Arizona State University  
Michael J. Saks  
Arizona State University - College of Law

**THE YALE LAW JOURNAL**

TOM R. TYLER

Viewing CSI and the Threshold of Guilt:  
Managing Truth and Justice in Reality and Fiction

Abstract: The CSI Effect. And what practitioners show that have Effect. We note different effects of whether the evidence that h acquittal rates Effects, which the reliability of CSI Effect. Find argue that court explanation for

Abstract: Two of a science, burden the hypothesis, conviction responds the trial, difference from their dist cons

glorify forensic can be delivered or (b) job puts these artist. The case for the trial evidence, evidence presented at statistically significant did not differ significantly specific to those whose

**CSI Effect**  
From Wikipedia, the free encyclopedia

It has been suggested that this article or section be merged with *CSI syndrome*. (Discuss)

raising crime victims' and jury members' real-world expectations of forensic science


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## Courts and Forensic Science

*“Judges and lawyers usually react to science with all the enthusiasm of a child about to get a tetanus shot. They know it’s painful and believe it’s necessary, but haven’t the foggiest idea how or why it works.”*

Black et al.: “Science and the Law After *Daubert*”  
*Texas Law Review* 1994.




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**Ronald Taylor**  
Served 12 years in Texas after faulty lab tests before trial.




August 19, 2010 : 258 EXONERATED

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'Conviction' — Starring Hilary Swank — Coming to Theaters October 15



**THE INNOCENCE BLOG**  
Updated Daily




**The Causes of Injustice**

Each of the 258 wrongful convictions overturned through DNA testing is unique, but most originate from the same common flaws in the criminal justice system. Innocence Project research into wrongful conviction cases helps pinpoint weaknesses within the system. Learn about the major causes of injustice, including misidentification, improper forensics, false confessions and informant testimony.

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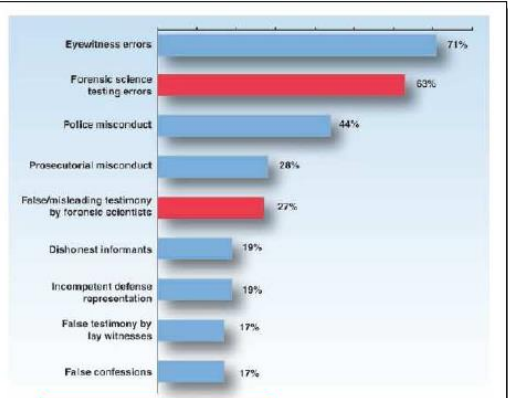
The Innocence Project is a national litigation and public policy organization dedicated to exonerating wrongfully convicted people through DNA testing and reforming the criminal justice system to prevent future injustice.

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## Forensic Science & Conviction Errors



prints, prints, core ences o sup- ed but aking exper- ist or e tra- regard d, and aliza- n: that been foren- e evi- to the 7, 8), ion of is as- fferent Thus, evably



Factor	Percentage
Eyewitness errors	71%
Forensic science testing errors	63%
Police misconduct	44%
Prosecutorial misconduct	28%
False/misleading testimony by forensic scientist	22%
Dishonest informants	19%
Incompetent defense representation	19%
False testimony by lay witnesses	17%
False confessions	17%

Fig. 1 Factors associated with wrongful conviction in 86 DNA exoneration cases, based on case analysis cases 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.

5 AUGUST 2005 VOL 309 SCIENCE www.sciencemag.org

## Major Errors

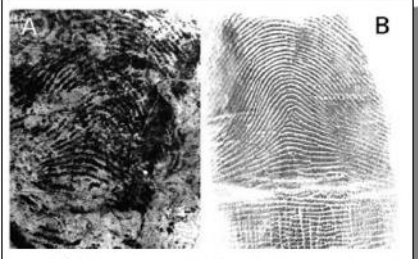
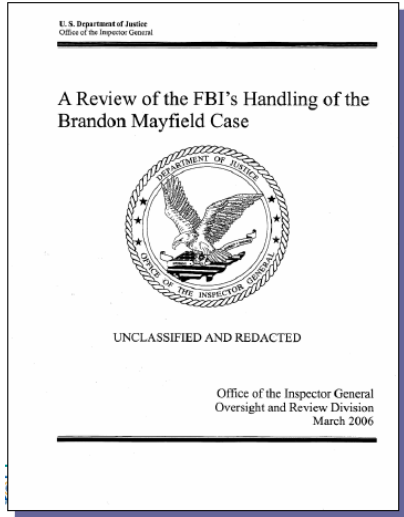


Fig. 4. (A) A latent fingerprint believed to belong to a terrorist involved in train bombings in Madrid, Spain, in March 2004. (B) A database print belonging to Brandon Mayfield of Portland, Oregon. On the basis of these prints (though not necessarily these very images), FBI fingerprint examiners erroneously identified Mayfield as the bomber (26). [Source: Problem Idents, onin.com/fp/problemidents.html#madrid]



## Media Impact



## Is Forensics really Science?

### EDITORIAL

#### Forensic Science: Oxymoron?

In detective novels and television series, criminals often get caught because they leave fingerprints at the scene. Well, art does imitate life; fingerprint analysis is widely used in U.S. courts and those of many other countries. But last year a funny thing happened to fingerprint evidence on the way to a conviction. Applying the standard set for the admissibility of scientific evidence by the U.S. Supreme Court in the 1993 Daubert case, Judge Louis Pollak ruled that an expert could not testify that the prints at a crime scene matched those of a suspect. Shock reverberated through the criminal justice community, until Judge Pollak induced a sigh of relief from district attorneys everywhere by saying that at least in this case, such testimony could be used after all.

The Supreme Court's Daubert standard has generated some ambiguity for the legal community, but the Court did list several criteria for qualifying expert testimony: peer review, error rate, adequate testing, regular standards and techniques, and general acceptance. Judge Pollak's initial finding was that the evidence flunked all but one. Some distinguished legal scholars think that he was right.

a figure of speech that combines two normally contradictory terms

It's not that fingerprint analysis is unreliable. The problem, rather, is that its reliability is unverified either by statistical models of fingerprint variation or by consistent data on error rates. Nor does

one interest—security and justice—would be furthered by a mere scientific and remote analyzing crimes. The mystery here is why the practitioners don't seem to want it!

Donald Kennedy  
Editor-in-Chief

www.sciencemag.org SCIENCE VOL 302 5 DECEMBER 2003



UNIVERSITY

## The New Paradigm

- Old paradigm: 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
- New paradigm: Rigorous proficiency testing
  - Scientific plausibility of technique followed and proper error rate analysis of the forensic technique used is expected

## The New Paradigm

# REVIEW

## The Coming Paradigm Shift in Forensic Identification Science

Michael J. Saks<sup>1</sup> and Jonathan J. Koehler<sup>2</sup>

Converging legal and scientific forces are pushing the traditional forensic identification in actual cases. <sup>1</sup> Changes in the law pertaining to the admissibility of expert evidence in court, together with the emergence of DNA typing as a model for a scientifically defensible approach to questions of shared identity, are driving the older forensic sciences toward a new scientific paradigm. <sup>2</sup>

Individualization scientists compared pairs of marks (handwriting, fingerprints, tool marks, hair, tire marks, bite marks, etc.), intuited whether the marks matched, and testified

Although lacking theoretical or empirical foundations, the assumption of discernible uniqueness offers important practical benefits

that different objects share a common set of observable attributes. Without the discernible

[We use the notion of paradigm shift not as a literal application of Thomas Kuhn's concept (9), but as a metaphor highlighting the transformation involved in moving from a pre-

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## The New Paradigm: Admissibility

- US Supreme Court (Daubert, 1993): expert testimony must be both:
  - Relevant
  - Reliable: conclusions derived from the scientific method:
    - Peer review, error rate, adequate testing, regular standards and techniques, general acceptance
- "General guidelines" can be summarized in:
  - Testability: accuracy/reliability, proficiency testing, data supported
  - Transparency: clear & detailed reporting, replicability, standards, motivation of each step of the analysis

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## The New Paradigm: DNA Reference

- DNA analysis has become the new "*golden standard*" in Forensic Identification Science:
    - Scientifically based, avoiding experience-based opinions
    - Clear and standard procedures
    - Probabilistic, avoiding hard match or non-match statements
    - *Two-stage approach* to assess the weight of the evidence:
      - *Similarity* factor (evidence vs suspect)
      - *Typicality* (or *rarity*) factor (evidence vs population)
- **Likelihood Ratio**

Bayesian methodology as model of clear, standard and probabilistic framework

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## Forensics: Challenges and Trends



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## The American Vision: NAS Report (1/2)

- Strengthening Forensic Science in the USA 2009
- Expert meetings between 2006 and 2009
- Challenge/problems identified:
  - Disparities in the Forensic Science Community
  - Lack of mandatory standardization/accreditation
  - Broad range of disciplines
  - **The need for research to establish limits and measures of performance**
  - Admission of Forensic Science Evidence

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## The American Vision: NAS Report (2/2)


- Recommendations:
  - Creation of NIFS:
    - Best practices, standards, research, education, methodologies, project funding, assessing new technologies
    - Protocols and standards for forensic practitioners
    - Code of Ethics
  - **Funding research in:**
    - **Validity studies**
    - **Reliability & accuracy & uncertainty measures**
    - **Enhancing forensic technologies**
    - Human bias
  - Independence between forensic labs and law enforcement agencies
  - Laboratory accreditation and individual certification (Q control)

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## The European Vision: ENFSI (1/2)



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### About ENFSI

**Mission Statement**

ENFSI has been established with the purpose of sharing knowledge, exchanging experiences and coming to mutual agreements in the field of forensic science. ENFSI is recognised as an expert group in the field of forensic sciences.

**Aim**

ENFSI is recognized as a pre-eminent voice in forensic science worldwide by ensuring the quality of development and delivery of forensic science throughout Europe. It will therefore:

- strengthen and consolidate ENFSI
- expand the membership throughout Europe while maintaining the development and credibility of ENFSI
- establish and maintain a working relationships with other similar organizations
- encourage all ENFSI laboratories to comply with best practice and international standards for quality and competence assurance

**Activities**

ENFSI activities include:

- organizing meetings and scientific seminars
- collaborative studies and proficiency tests
- advising relevant partners on forensic issues
- publishing best practice manuals and glossaries of forensic terms in several languages

**SEARCH**

**ENFSI MEMBERS LOGIN**

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**AGENDA**

The tri-annual meeting of the International Council on Alcohol, Drugs and Traffic Safety  
2010-08-22 Oslo, Norway

20th International Symposium on the Forensic Sciences  
2010  
2010-09-05 Sydney, Australia

Forensic IT Working group meeting  
2010-09-14 Moscow, Russia

6th EDEWG Conference



## The European Vision: ENFSI (2/2)



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  - EXPLOSIVES
  - FINGERPRINT

### Fingerprint

**Aims and objectives**

The European Fingerprint Working Group (EFP-WG) promotes development and improvement in the fields of fingerprint detection, imaging and comparison through

- Regular meetings, providing opportunities for the development of professional relationships, training through presentations and workshops, and exchanges of experience.
- Awareness and collaboration in research and development.
- Promotion of quality management through publication of a Best Practice Manual, support of external accreditation and collaborative tests.

**Structure**

The EFP-WG is managed and organized by a Steering Committee elected from the members.

There are two permanent Sub Groups:

- Detection: formed of members who specialize in the location and recovery of fingerprints.
- Identification: formed of members who undertake comparison of fingerprints.

Sub Committees are formed to consider specific issues, for example collaborative testing.

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Forensic IT Working group



## AFIS: Performance



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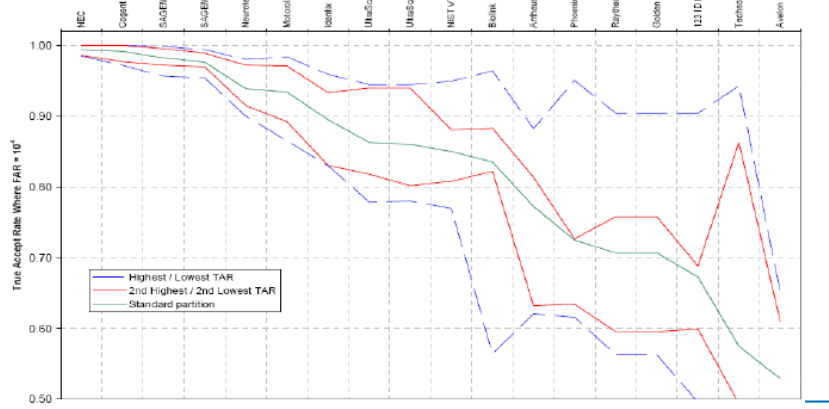
### Performance of AFIS

- Fingerprint recognition performance:
  - Usually tested with good quality fingerprints searched against single impressions
  - Needs to be tested in more realistic conditions, with real latent prints against ten-print databases
- Latent fingermarks are distorted, incomplete and may have artifacts
  - Better automatic feature extraction
- Forensic biometric systems need be analyzed to understand the variation in performance when the working conditions are not optimal
  - Following the real forensic casework
  - Using real forensic databases
  - Identifying significant system parameters

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## AFIS Performance: Impressions

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



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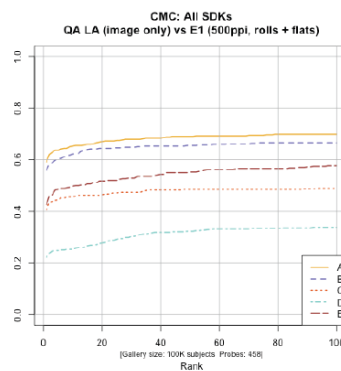
## AFIS Performance: Latents

### NIST ELFT TR-7577 (2009)

ELFT Phase II	
Rank 1 against 100K fingerprints	
NEC	97.2
Cogent	87.8
SPEX	80.0
Motorola	79.3
L1 Identity Solutions	78.8
Peoplespot	67.9
Sonda	28.5
BioMG	27.5

### NIST ELFT-EFS Preliminar TR (2010)

ELFT-EFS	
LA - Image only	
Rank 1 against 1M fingerprints	
Sagem	62.2
NEC	61.2
Cogent	48.3
Warwick	47.2
Sonda	25.1



- ELFT Phase II → Good Q latents
- ELFT-EFS → Realistic latents, large size DB, limited search time

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## Case Study: AFIS Performance Analysis



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## Fingerprint Databases (1/2)

### ■ Queries:

- 50 latent fingerprint marks
- 50 plain fingerprint impressions
- 50 rolled fingerprint impressions



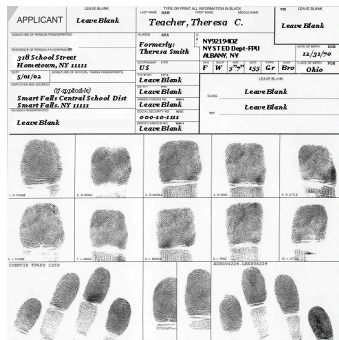
**All the fingerprints are extracted from the Guardia Civil database and belong to real forensic cases**

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## Fingerprint Databases (2/2)

- Background database:**

Real ten-print card database (more than 2.5 million)

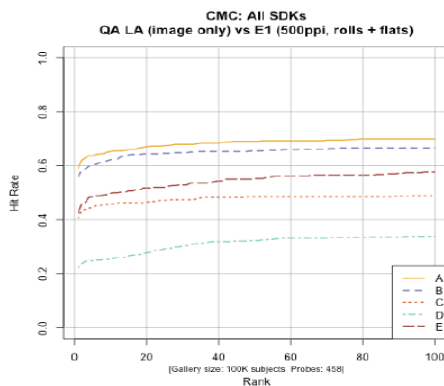


All the fingerprints are extracted from the Guardia Civil database and belong to real forensic cases

## Fingerprint Recognition System

- State-of-the-art AFIS (only minutiae-based), one of the top ranked in NIST ELFT-EFS 2010.

ELFT-EFS	
LA - Image only	
Rank 1 against 1M fingerprints	
Sagem	62.2
NEC	61.2
Cogent	48.3
Warwick	47.2
Sonda	25.1



Extracted from: NIST ELFT-EFS Evaluation. Preliminary Report.

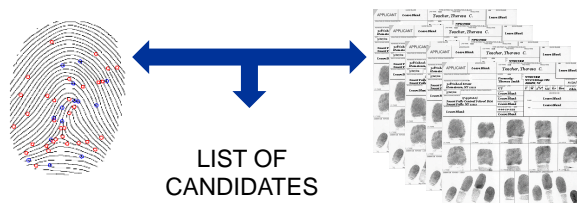
## Experiments

### ❖ Experiments with latent fingerprints

#### Feature Extraction

1. Automatic minutiae extraction made by the system
2. Maximum number of minutiae manually marked by a latent expert
3. Subset of 12 minutiae selected among the manually marked
4. Subset of 8 minutiae selected among the manually marked

#### Matching



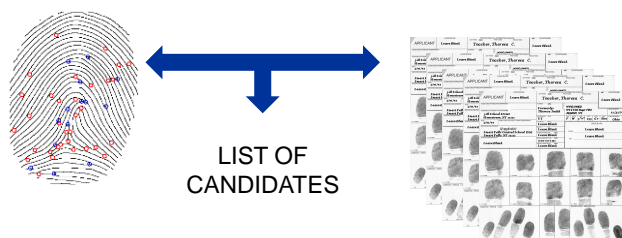
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## Experiments

### ❖ Experiments with fingerprint impressions

- ❑ Automatic feature extraction (real forensic casework)
- ❑ Separation of two groups of queries: rolled and plain impressions

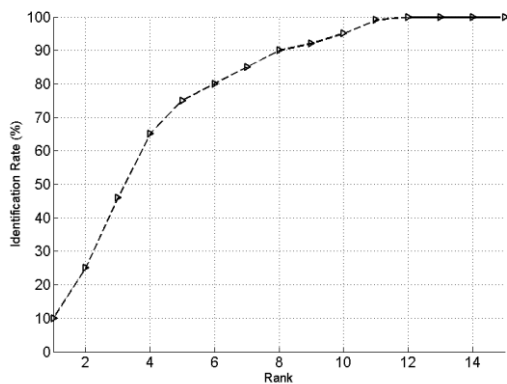
#### Matching



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## Results

### CMC Curves (Cumulative Match Characteristic)

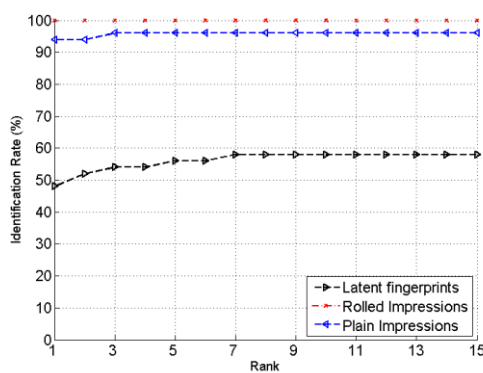


Plots the rank- $n$  identification rate against  $n$ , for  $n=1,2,\dots,M$

## Impressions vs Latents

Average number of minutiae:

- ❖ Rolled impressions: 83.3
- ❖ Plain Impressions: 44.16
- ❖ Latent fingerprints: 31.2

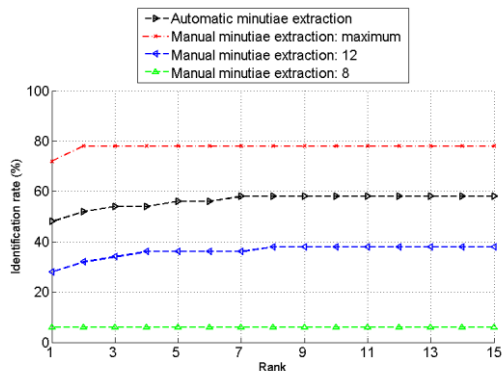
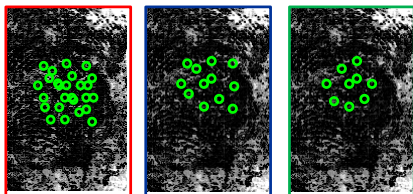


	Rolled	Plain	Latent
Rank 1	100%	94%	48%
Rank > 15	0%	4%	42%

## Latents: Number of Marked Minutiae (Manual vs Auto)

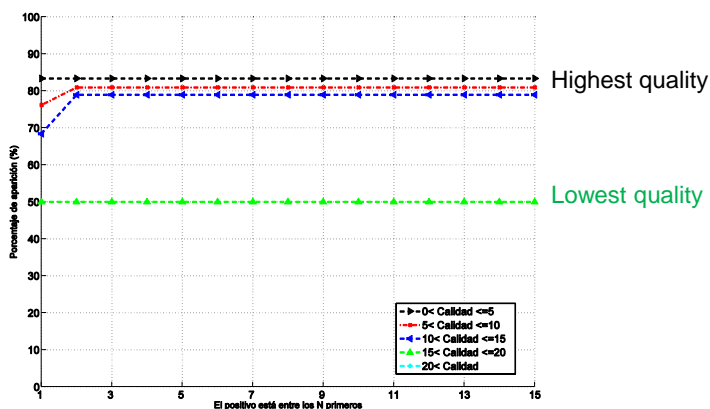
Average number of minutiae:

- ❖ Automatic extraction: 31.2
- ❖ Manual extraction: 25.2



MINUTIAE	MAX. MANUAL	MAX. AUTO	12 MANUAL	8 MANUAL
Rank 1	72%	48%	28%	6%
Rank > 15	22%	42%	62%	94%

## Latents: Quality Analysis





## Case Study Conclusions

- ❑ The performance of a state-of-the-art AFIS was evaluated:
  - ❖ With a fingerprint database from real forensic cases
  - ❖ Following protocols used in forensic casework
    - Ten print national database with more than 2,5 million impressions
- ❑ The performance with latent fingerprints is considerably low
  - ❖ Manual extraction performance is still far better than automatic extraction for these kind of prints
- ❑ Automatic extraction leads to better performance with fingerprint impressions than with latent prints
  - ❖ Quality and the number of minutiae are critical for the feature extraction
  - ❖ Rolled prints better than plain prints due to a higher number of minutiae (even with more distortion)

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## Conclusions



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## Conclusions

- ❑ Forensic Fingerprint ID strongly based on human expertise
  - ❖ ACE-V
  - ❖ AFIS setup and marking
- ❑ Current efforts in converting the expert practice in a scientific discipline
- ❑ Research problems for biometrics:
  - ❖ Validity studies
  - ❖ Reliability & accuracy & uncertainty measures
  - ❖ Enhancing image processing and pattern recognition technologies
- ❑ AFIS performance: impressions vs latents
- ❑ Case study: realistic AFIS performance (2.5M 10-print DB)
  - ❖ Impressions vs latents
  - ❖ Number of marked minutiae
  - ❖ Image quality

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## Further Reading:

D. Ramos, R. P. Krish, J. Fierrez and D. Meuwly, "From Biometric Scores to Forensic Likelihood Ratios", Massimo Tistarelli and Christophe Champod (Eds.), *Handbook of Biometrics for Forensic Science*, Springer, 2017.

R. P. Krish, J. Fierrez, D. Ramos, et al., "Pre-Registration of Latent Fingerprints based on Orientation Field", *IET Biometrics*, June 2015.

M. Puertas, D. Ramos, J. Fierrez, et al., "Towards a Better Understanding of the Performance of Latent Fingerprint Recognition in Realistic Forensic Conditions", in *Proc. Intl. Conf. on Pattern Recognition, ICPR*, Aug. 2010.

J. Gonzalez-Rodriguez, J. Fierrez-Aguilar, et al., "Bayesian Analysis of Fingerprint, Face and Signature Evidences with Automatic Biometric Systems", *Forensic Science International*, Dec. 2005.

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