Biometric System Laboratory

University of Bologna - ITALY

http://biolab.csr.unibo.it

Biometric Systems are automated methods of verifying or recognizing the identity of a living person on the basis of some physiological characteristics, like a fingerprint or iris pattern, or some aspects of behavior, like handwriting or keystroke patterns.

Team

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Alessandro Alessandroni, External advisor

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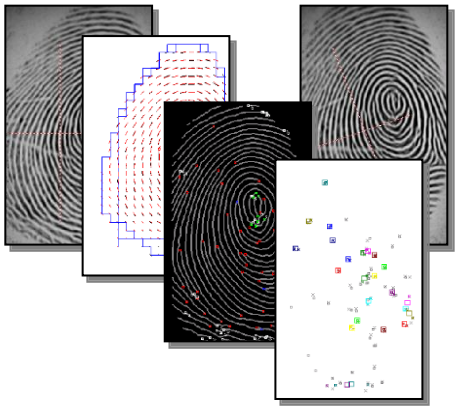
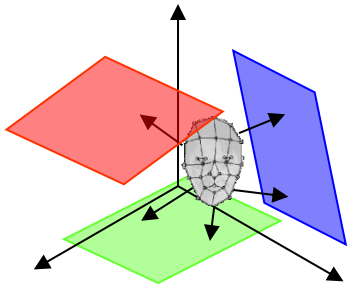
Research Topics

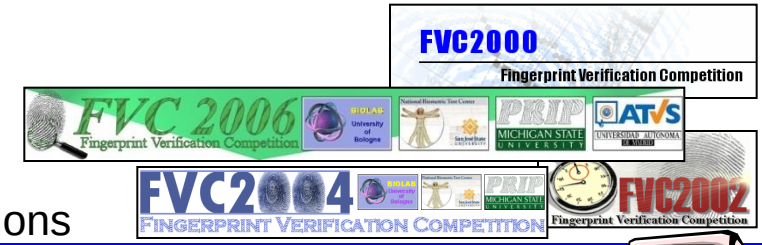
- Fingerprints
  - Processing and Matching
  - Classification and Indexing
  - Synthetic Generation
  - Fake/Aliveness Detection
  - Scanner Quality

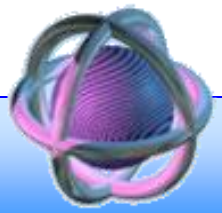


- Face
  - Localization
  - Recognition



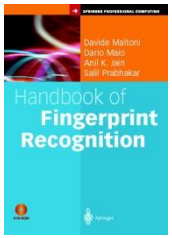
- Hand
  - Geometry and Dermatoglyphics
  - Palmprint Recognition
- Performance Evaluation
  - Theoretical Models
  - Fingerprint Verification Competitions





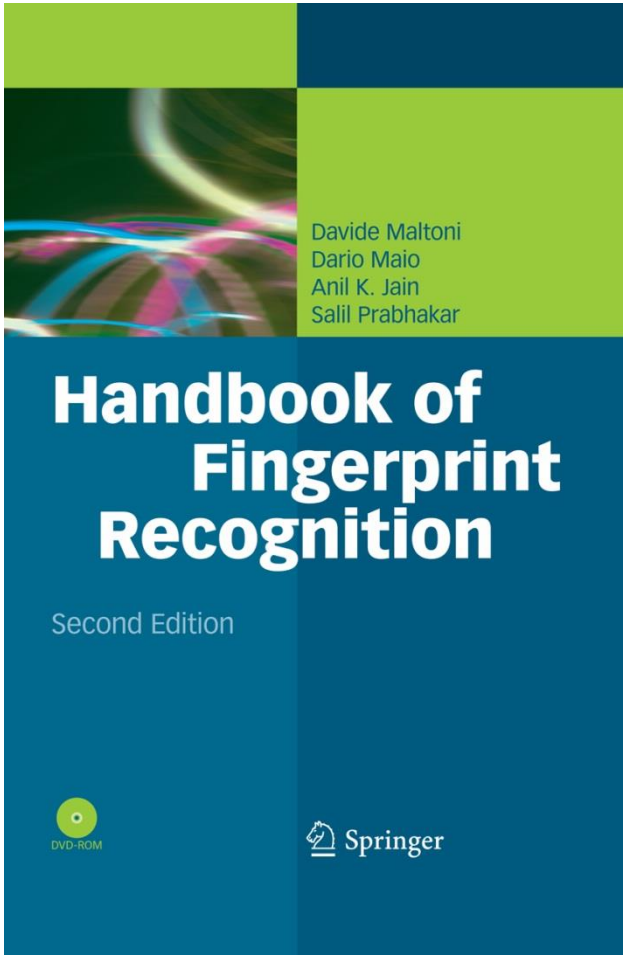
The Handbook of Fingerprint Recognition

- The book includes results of BioLab research and provides an updated snapshot of the current state-of-the-art in fingerprint recognition



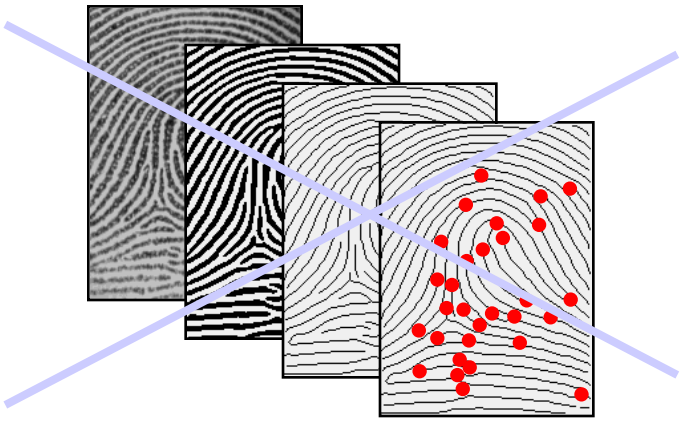
The first monographic book on automated approaches to fingerprint recognition (published by Springer in 2003)

Second edition (a major update) published in 2009



Fingerprints: minutiae detection

Traditional approach

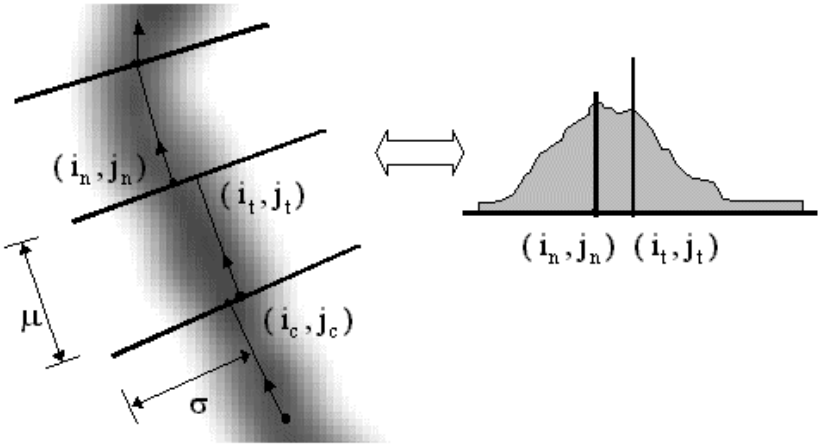


No !

- A lot of information may be lost during the binarization process.
- Binarization and thinning are time-consuming.

Direct gray-scale minutiae detection

*The basic idea is to **follow the ridge lines** on the **gray-scale image**, by "sailing" according to the fingerprint **directional image**. A set of starting points is determined by superimposing a square-meshed grid on the gray-scale image. For each starting point, the algorithm keeps following the ridge lines until they **terminate** or **intersect** other ridge lines.*

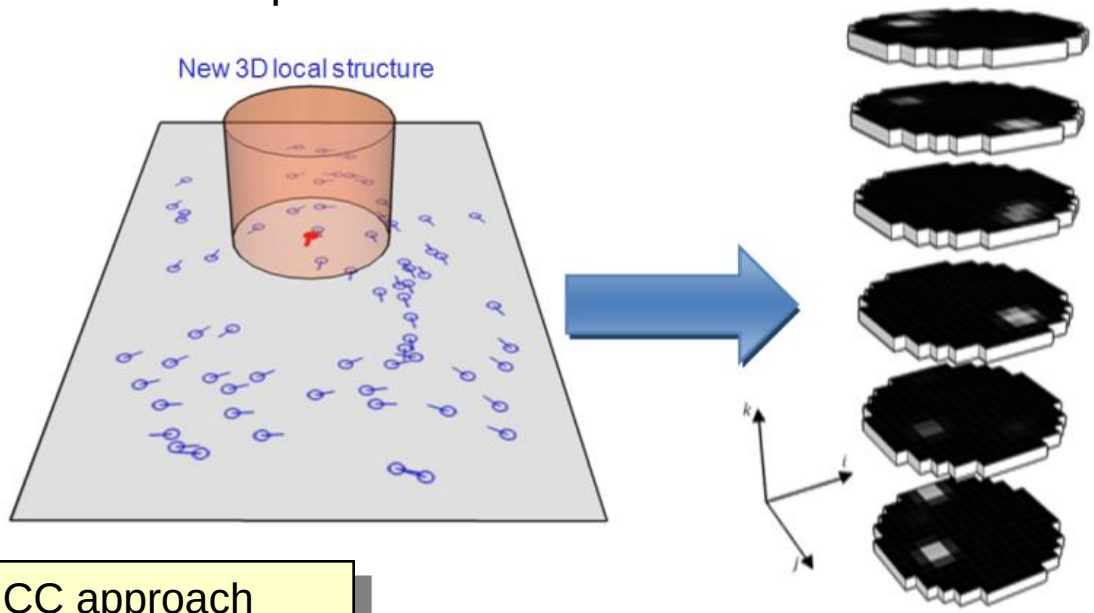


In 1997 BioLab published the first Direct Gray-scale detection approach

Fingerprints: MCC representation

- *MCC* (Minutia Cylinder Code) is a novel minutiae representation and matching techniques
  - Fast and accurate
  - Bit-based, portable on light architectures
  - Suitable for template protection techniques

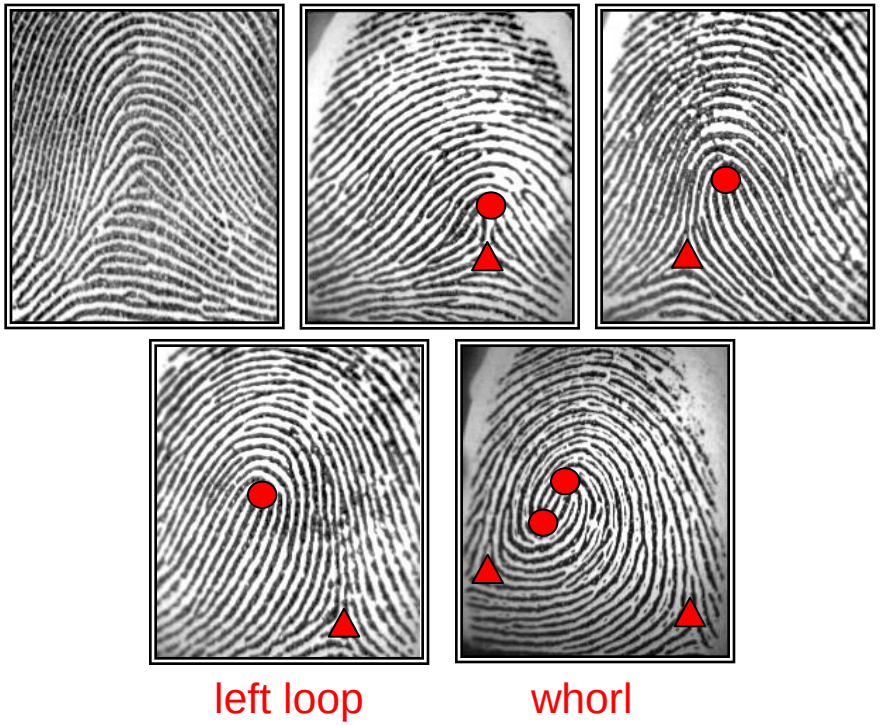
- Patent N. ITBO2009A000149



In 2010 BioLab published MCC approach

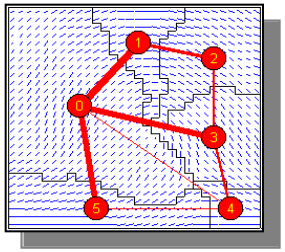
Fingerprints: classification

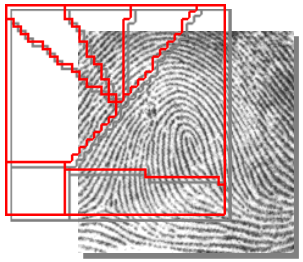
The five main fingerprint classes



Approaches proposed:

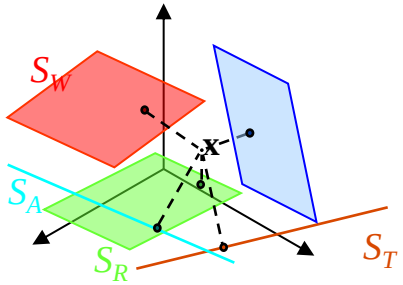
Inexact graph matching





Dynamic masks

MKL-based

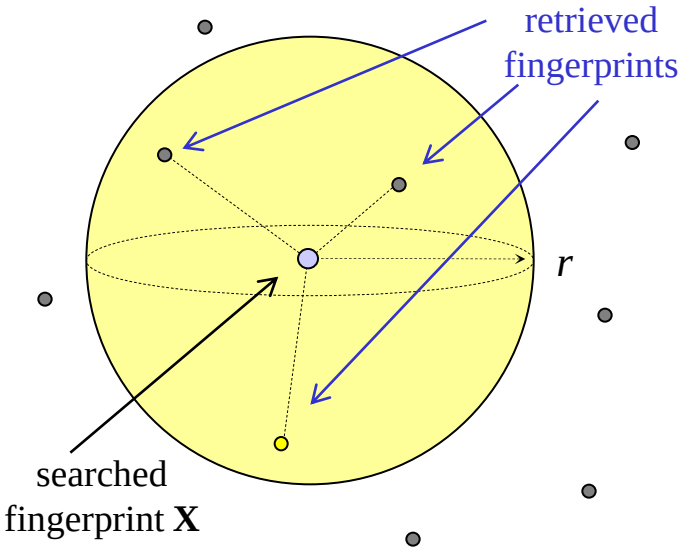


In 2002 BioLab published the first fingerprint classification algorithm able to meet the FBI fingerprint classification requirements

Fingerprints: indexing

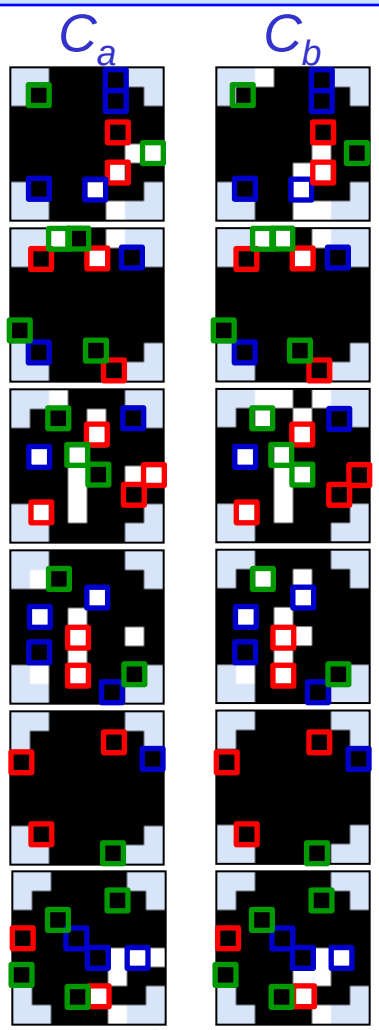
- *Exclusive classification* is not a good indexing method for retrieval on large databases:
  - the number of classes is small
  - fingerprints are non-uniformly distributed
  - “ambiguous” fingerprints cannot be reliably assigned to a unique class

- *Continuous classification* associates a *multidimensional point* to each fingerprint and uses *spatial queries* for fingerprint retrieval by similarity.



In 1997 BioLab published the first fingerprint continuous classification approach

Fingerprints: MCC-based indexing



The idea behind the *Locality-Sensitive Hashing* (LSH) *is that if two binary vectors are similar, then after a "projection" into a lower-dimensional subspace, they will remain similar.*

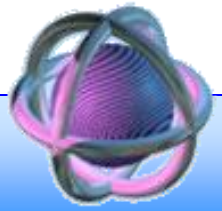
$$H_1 = \{23, 39, 56, 59, 103, 118, 137, 144, 146, 185, 200, 216, 218, 250, 278, 305\}$$
$$H_2 = \{3, 8, 42, 45, 61, 94, 113, 123, 170, 175, 191, 207, 225, 281, 290, 292\}$$
$$H_3 = \{4, 33, 52, 53, 86, 97, 109, 125, 134, 161, 203, 259, 268, 272, 294, 304\}$$

The set of indices defines a hash function that maps a cylinder to the natural number corresponding to its binary representation.

0 1 0 1 0 1 1 0 1 1 1 0 0 0 0 1	$f_{H_1}(C_a) = 22241$
0 1 0 1 0 1 1 0 1 1 1 0 0 0 0 1	$f_{H_1}(C_b) = 22241$
0 0 0 1 0 0 0 1 1 1 0 0 0 0 0 1	$f_{H_2}(C_a) = 4545$
0 0 0 1 0 0 0 1 1 1 0 0 0 0 0 1	$f_{H_2}(C_b) = 4545$
0 1 1 0 0 0 0 1 0 0 0 0 0 0 0 0	$f_{H_3}(C_a) = 24832$
0 0 1 1 0 0 1 1 1 1 0 0 0 0 0 0	$f_{H_3}(C_b) = 13248$

The similarity between two cylinders can be estimated by counting the number of collisions under many hash functions.

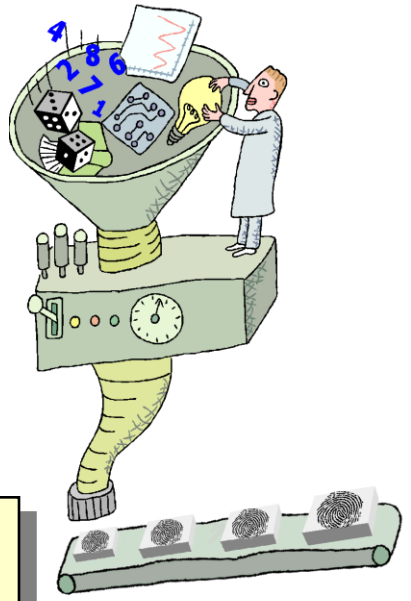
In 2011 BioLab published a novel indexing approach based on MCC



Fingerprints: synthetic generation

- Collecting large databases of fingerprint images is:
  - expensive both in terms of money and time
  - boring for both the people involved and for the volunteers, which are usually submitted to several acquisition sessions at different dates
  - problematic due to the privacy legislation which protects such personal data

A method able to *artificially* generate realistic fingerprint-images could be used in several contexts to *avoid collecting databases of real fingerprints*



In 2000, BioLab published the first approach able to generate realistic fingerprint images (SFinGe)

Fingerprints: fake detection

- One of the most recent challenges: fake finger detection
- Two novel approaches (to be published in 2006)
  - Distortion analysis (Patent IT #BO2005A000399)
    - The user is required to place a finger onto the scanner surface and to apply some pressure while rotating the finger

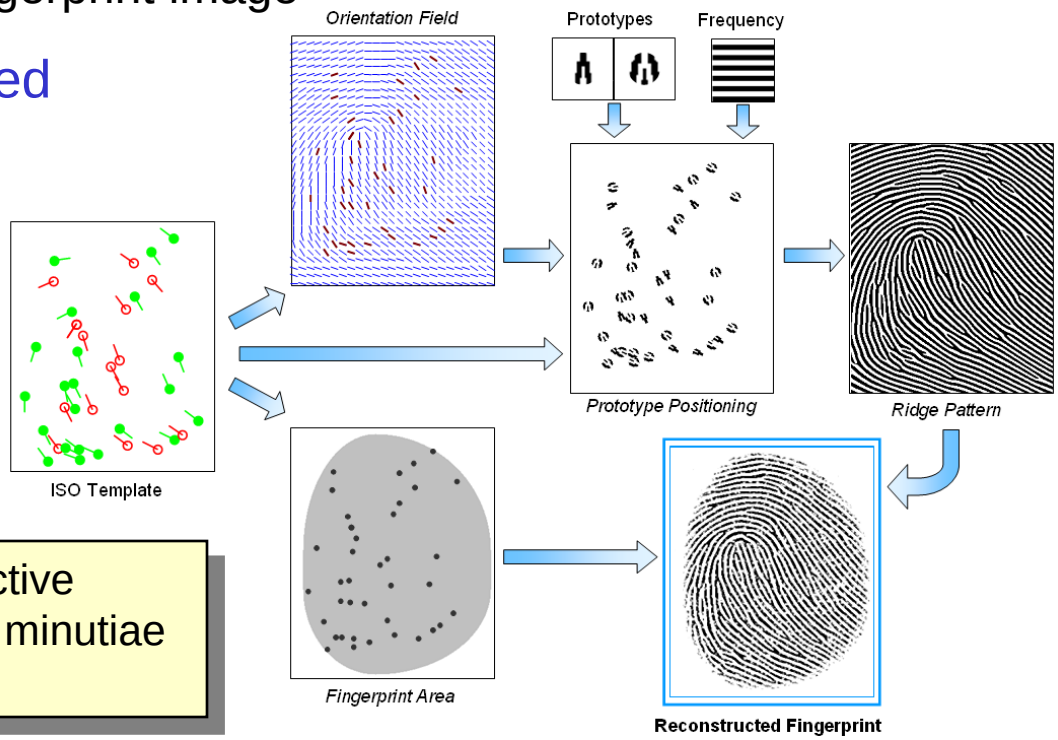
Real finger

Fake finger

  - Odor analysis (Patent IT #BO2005A000398)
    - Using one or more odor sensors (*electronic noses*) to detect materials usually adopted to make fake fingers

Fingerprints: reconstruction from templates

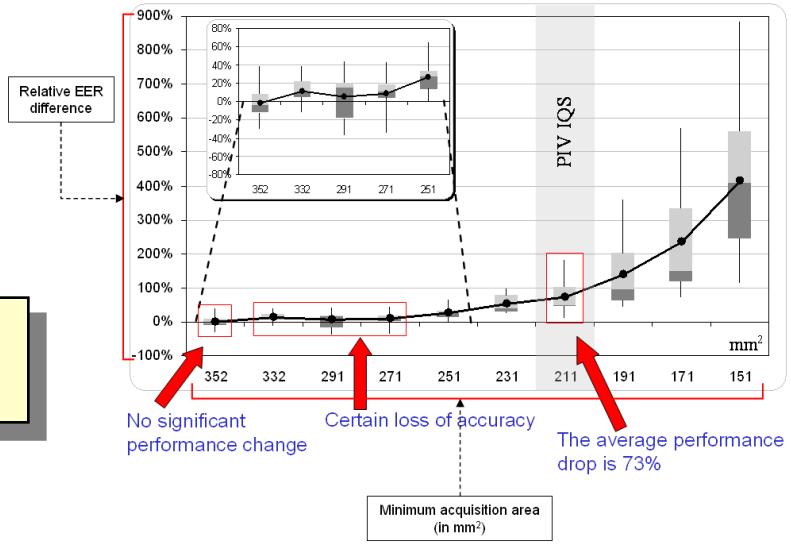
- Can minutiae templates be reverse-engineered?
  - The template extraction procedure has been traditionally considered similar to a one-way function, since many researchers and practitioners in the biometric field postulated that a template does not include enough information to reconstruct a fingerprint image
- A reconstruction approach based on three steps:
  - Fingerprint area estimation
  - Orientation field estimation
  - Ridge-line pattern generation



In 2007, BioLab published the first effective reconstruction approach from standard minutiae templates

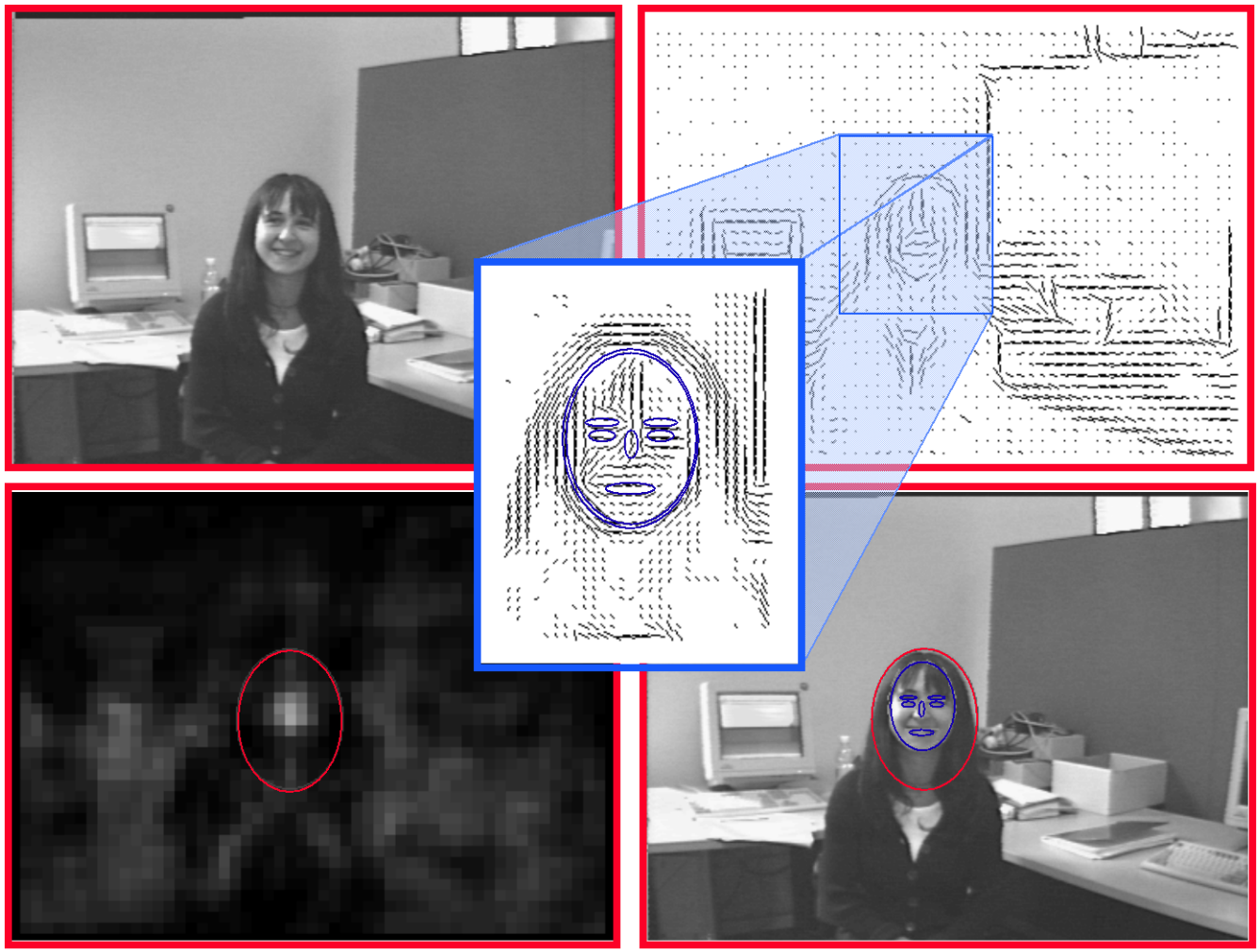
Fingerprint scanners: operational quality

- How to evaluate the impact of each quality parameter (e.g. acquisition area, resolution accuracy, MTF) on the matching performance?
- Operational fingerprint scanner quality
  - The ability of acquiring images that *maximize* the *accuracy* of automated fingerprint recognition systems
- A large experimentation to understand the effects of the various quality parameters has been carried out



In 2008, BioLab introduced a new operational definition of fingerprint scanner quality

Face: localization



Directional Image computation

Approximate location

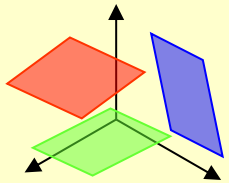
Directional Image refining

Fine location & face verification

The fast face location algorithm was published by BioLab in 1998

Face: recognition

Enrollment



MKL subspace learning

Template

Face location and normalization

Feature extraction

Distances from MKL subspaces

Classification

Result

Recognition/Verification

MKL-based face recognition: published by BioLab in 2002

Performance evaluations: FVC

- FVC is a technology evaluation of algorithms
  - Not complete systems, but only algorithms
  - Not a performance evaluation in a real application
- Main aims
  - Track the state-of-the-art in fingerprint recognition
  - Provide updated benchmarks and a testing protocol for fair and unambiguous evaluation of fingerprint verification algorithms

FVC onGoing

FVC2000 was the first international competition for fingerprint verification algorithms

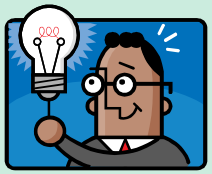
Performance evaluations: FVC-onGoing

Web-based automatic evaluation of fingerprint recognition algorithms

- Participants can be: companies, academic research groups, or independent developers
- Algorithms are tested on sequestered datasets and results are reported using well-known performance indicators and metrics
- Fully automated:
  1. The system automatically tests the algorithm submitted by a participant
  2. The participant sees the results in its “private area”
  3. Then the participant may decide to publish the results in the public section of the FVC-onGoing web site

http://biolab.csr.unibo.it/FVConGoing

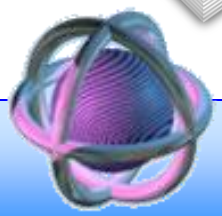
FVC-onGoing: Participants and Algorithms

Registered Participants		Jun 2010	Jun 2011
	Academic Research Groups	27	44
	Companies	52	73
	Independent Developers	75	188

From July 2009 to June 2011

Algorithm Evaluated		Jun 2010	Jun 2011
	Fingerprint Verification	150	599
	Fingerprint ISO Template Matching	298	542

Results Published		Jun 2010	Jun 2011
	Fingerprint Verification	11	26
	Fingerprint ISO Template Matching	13	26



Main collaborations in EU projects

http://www.biosec.org

http://www.biosecure.info

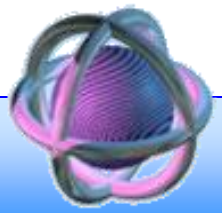
FIDELITY

Fast and trustworthy Identity Delivery and check with ePassports leveraging Traveller privacy

http://www.fidelity-project.eu/

INGRESS

Innovative Technology for Fingerprint Live Scanners

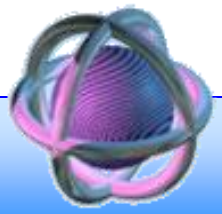


Collaboration with the Italian government

- BioLab scientifically supports the Italian National Centre for Information Technology in the Public Administration (CNIPA) within the established “Task Force on Biometrics” to:
  - Provide guidelines and support to the PA, and in particular to: Istituto Poligrafico e Zecca dello Stato, Min. Giustizia, Min. Interni, Min. Esteri, Esercito, ...
  - Test and certify biometric solutions
- BioLab members are coauthors of the following “Quaderni CNIPA”:
  - N.9: Linee guida per l’impiego delle tecnologie biometriche nelle pubbliche amministrazioni
  - N.17: Linee guida per l’impiego delle tecnologie biometriche nelle pubbliche amministrazioni. Indicazioni operative

Other collaborations

- Academic
  - Michigan State University (Prof. Anil Jain)
  - San Jose State University (Prof. Jim Wayman)
  - Hong Kong Polytechnic University (Prof. David Zhang)
  - Universidad Autnoma de Madrid (Prof. Javier Ortega Garcia)
  - Tsinghua University (Prof. Jie Zhou and Dr. Jianjiang Feng)
- Industrial
  - Development of sensors and algorithms (Atmel – France, Biometrika – Italy, Siemens – Germany, STMicroelectronics – USA)
  - Support for the evaluation and certification of biometric systems (G&D – Germany and other companies)
  - Licensing of the SFinGe synthetic generator (more than 60 organizations, including Accenture, Nokia, Infineon, Cross Match, Mitsubishi, NEC, and some US government departments)



References

- Books
  - *Handbook of Fingerprint Recognition*, by D. Maltoni, D. Maio, A.K. Jain and S. Prabhakar, Springer, Second Edition, 2009.
  - *Biometric Systems - Technology, Design and Performance Evaluation* by J.L. Wayman, A.K. Jain, D. Maltoni and D. Maio (Eds), Springer, 2005.
- Journal papers
  - D. Maio and D. Maltoni, *Direct Gray-Scale Minutiae Detection in Fingerprints*, IEEE Transactions on PAMI, 1997.
  - R. Cappelli, A. Lumini, D. Maio and D. Maltoni, *Fingerprint Classification by Directional Image Partitioning*, IEEE Transactions on PAMI, 1999.
  - R. Cappelli, D. Maio and D. Maltoni, *Multi-space KL for Pattern Representation and Classification*", IEEE Transactions on PAMI, 2001.
  - R. Cappelli, D. Maio, D. Maltoni, J.L. Wayman and A.K. Jain, *Performance Evaluation of Fingerprint Verification Systems*", IEEE Transactions on PAMI, 2006.
  - R. Cappelli, A. Lumini, D. Maio and D. Maltoni, *Fingerprint Image Reconstruction from Standard Templates*, IEEE Transactions on PAMI, 2007.
  - R. Cappelli, M. Ferrara and D. Maltoni, *On the Operational Quality of Fingerprint Scanners*, IEEE Transactions on IFS, 2008.
  - R. Cappelli and D. Maltoni, *On the Spatial Distribution of Fingerprint Singularities*, IEEE Trans. on PAMI, 2009.
  - R. Cappelli, M. Ferrara and D. Maltoni, *Minutia Cylinder-Code: a new representation and matching technique for fingerprint recognition*, IEEE Trans. on PAMI 2010.
  - R. Cappelli, M. Ferrara and D. Maltoni, *Fingerprint Indexing based on Minutia Cylinder-Code*, IEEE Trans. on PAMI, 2011.
  - R. Cappelli, M. Ferrara and D. Maio, *Candidate List Reduction based on the Analysis of Fingerprint Indexing Scores*, IEEE Trans. on IFS, 2011.