
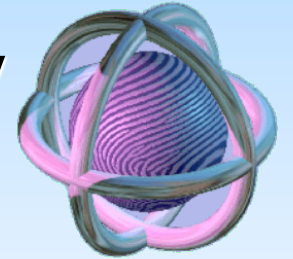


Raffaele Cappelli, Davide Maltoni

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<http://biolab.csr.unibo.it>

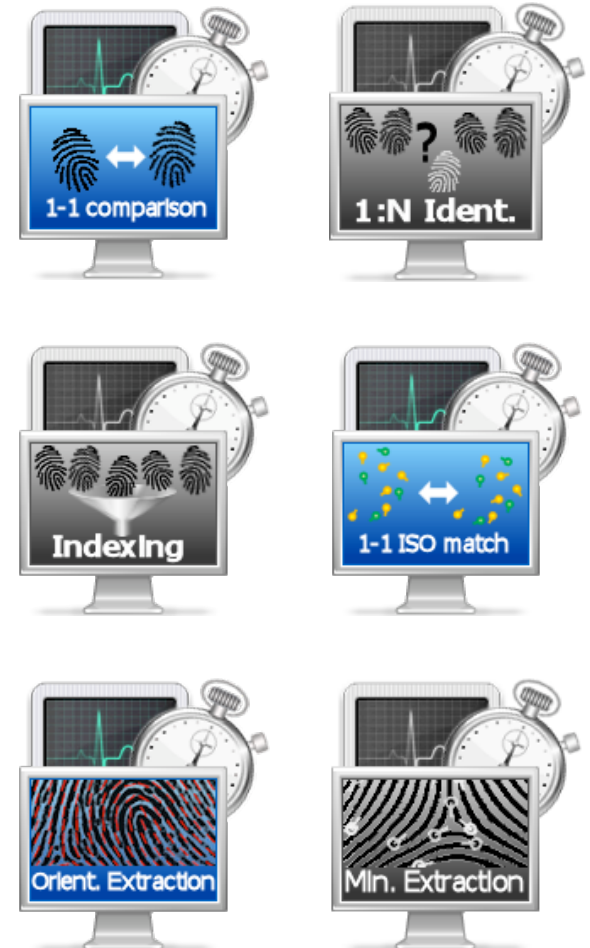


FVC-onGoing

On-line Evaluation of
Fingerprint Recognition Algorithms

Outline

- FVC: Fingerprint Verification Competitions
 - Background
 - What's new in FVC-onGoing
- How FVC-onGoing works
 - Architecture of the system
 - An example of evaluation
- Benchmark areas and benchmarks
 - Fingerprint verification
 - ISO template matching
 - Fingerprint orientation Extraction
- The next steps
 - New benchmark areas planned



Fingerprint Verification Competitions

- FVC: Technology Evaluations of Fingerprint Verification Algorithms
- Since 1999, when we started organizing FVC2000:
 - Four competitions: FVC2000, FVC2002, FVC2004, FVC2006
 - A total of 179 algorithms were evaluated
 - A total of 16 databases were collected and made available



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
- Main aim:
 - Track the advances in fingerprint recognition technologies, through continuously updated independent testing and reporting of performances on given benchmarks



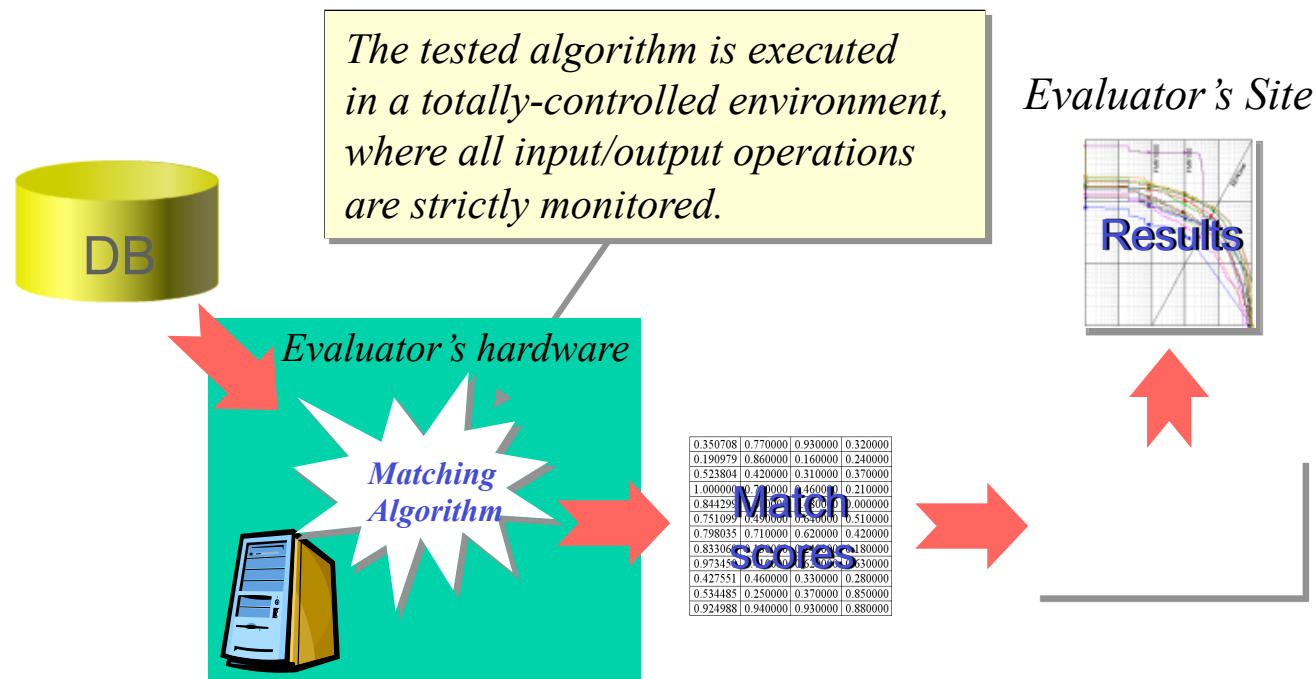
What's new in FVC-onGoing

- Previous FVC initiatives were organized as “competitions”
 - Specific calls and Fixed time frames
- FVC-onGoing is:
 - An “on going competition” always open to new participants
 - Datasets will remain sequestered
 - An evolving online repository of benchmarks, evaluation metrics and results
 - However the benchmark datasets will not evolve over time; in case new datasets will be added in the future, they will form a different benchmark (or a new version of an existing one)
- Not only limited to fingerprint verification algorithms:
 - Ad hoc benchmarks for testing specific modules of fingerprint verification systems are being made available:
 - Orientation Image Extraction (already available)
 - Fingerprint indexing
 - Minutiae Extraction

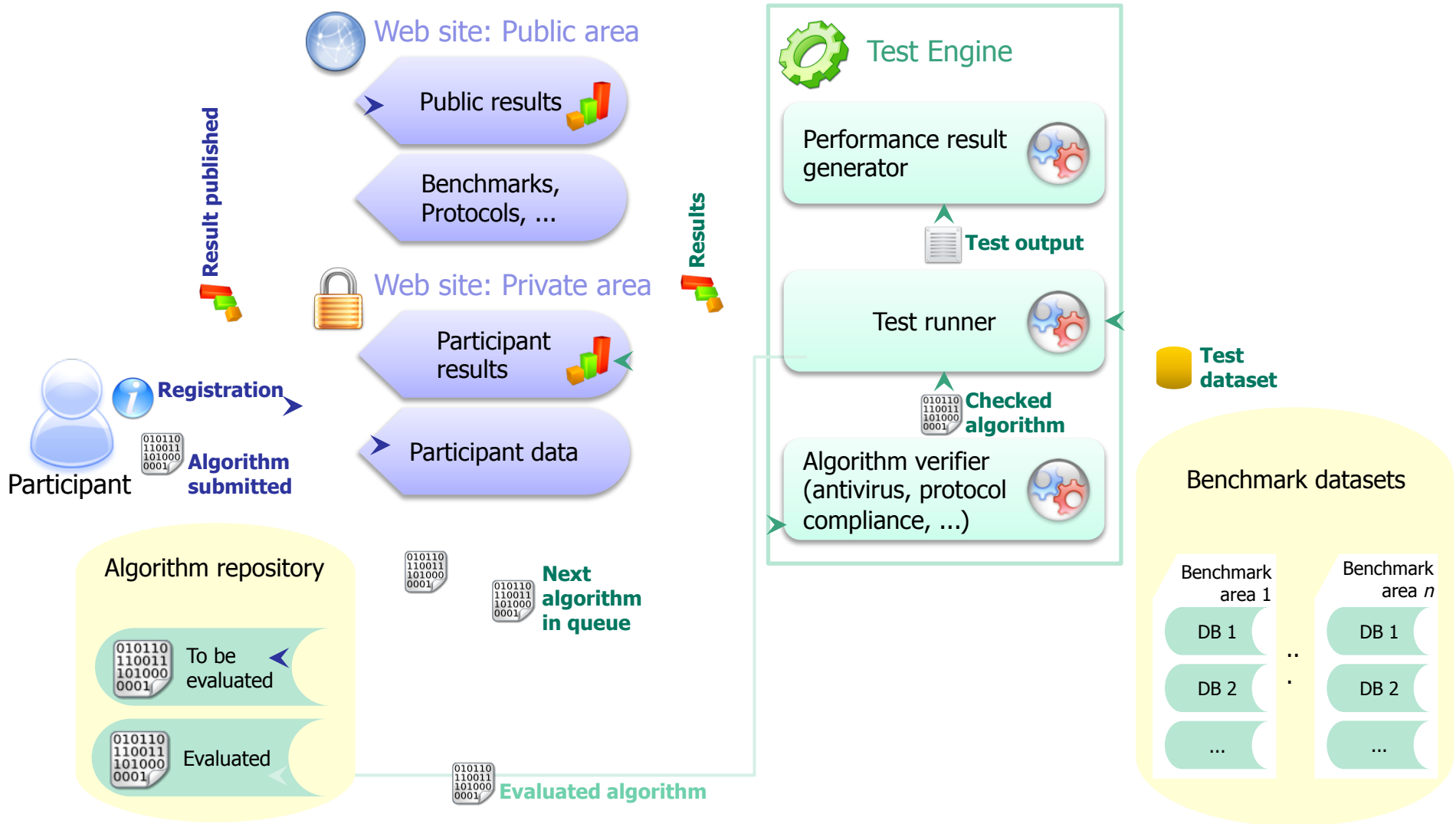


FVC-onGoing: Testing procedure

- As in previous FVCs, the testing procedure is Strongly Supervised
 - Protocol: *binary executable programs* compliant to a given input/output protocol are tested on the evaluator's hardware
 - Results: generated by the evaluator from the matching scores obtained during the test



FVC-onGoing: Workflow



An example...

Public area

- Home
- Background
- Benchmarks
- Register
- Published Results

Participant area

- Login
- Upload
- Pending Algorithms
- Tested Algorithms
- Download
- Past editions

FVC2006

FVC2004

FVC2002

FVC2000

FVC-onGoing: on-line evaluation of fingerprint recognition algorithms

FVC-onGoing is a web-based automated evaluation system for fingerprint recognition algorithms. Tests are carried out on a set of sequestered datasets and results are reported on-line by using well known performance indicators and metrics.

The aim is to track the advances in fingerprint recognition technologies, through continuously updated independent testing and reporting of performances on given benchmarks. The algorithms are evaluated using strongly supervised approaches to maximize trustworthiness.

FVC-onGoing is the evolution of FVC: the international Fingerprint Verification Competitions organized in 2000, 2002, 2004, and 2006.

Submission and Publication policy

Interested companies, academic research groups, and independent developers can register for an account on this web site and submit an algorithm to a given benchmark. The system will test the algorithm and the participant will see the results in its private area. Then the participant may decide to publish the results of its algorithm on the FVC-onGoing public result section, where they will be visible to any other web user.

Current status of the project

The system is currently under a beta-testing phase: only invited beta testers can submit algorithms.

The official start of FVC-onGoing is scheduled in June 2009, in conjunction with ICB2009.

Organization

- Biometric System Laboratory team (*University of Bologna, Italy*)
 - D. Maio
 - D. Maltoni
 - R. Cappelli
 - A. Franco
 - M. Ferrara
 - I. Palamkin






FVC-onGoing: on-line evaluation of fingerprint recognition algorithms

Benchmark areas and benchmarks

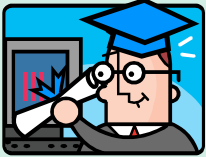


- FVC-onGoing benchmarks are grouped into Benchmark Areas
- All the benchmarks of a given benchmark area:
 - Address the same (sub)problem
 - Share the same evaluation protocol
- Each benchmark is based on a sequestered dataset that will not evolve over time
 - In case new datasets will be added in the future, they will form a different benchmark (or a new version of an existing one).
 - Only results obtained on the same benchmark are comparable.
 - A participant may submit more algorithms to the same benchmark
 - But there is a minimum break (e.g. one month) between consecutive submissions
- Currently available benchmark areas:
 - FV: fingerprint verification using proprietary templates
 - FMISO: fingerprint matching using ISO/IEC 19794-2 templates
 - FOE: fingerprint orientation extraction (orientation image)



Currently available benchmarks





Area	Benchmark	Description
 <p>FV Fingerprint Verification</p>	FV-TEST	A simple dataset useful to test algorithm compliancy with the testing protocol
	FV-STD-1.0	Fingerprint images acquired in operational conditions using high-quality optical scanners
	FV-HARD-1.0	Difficult cases (noisy images, distorted impressions, etc.): more challenging
 <p>FMISO Fingerprint ISO Template Matching</p>	FMISO-TEST	A simple dataset useful to test algorithm compliancy with the testing protocol
	FMISO-STD-1.0	Fingerprint images acquired in operational conditions using high-quality optical scanners
	FMISO-HARD-1.0	Difficult cases (noisy images, distorted impressions, etc.): more challenging
 <p>FOE Fingerprint Orientation Extraction</p>	FOE-TEST	A simple dataset useful to test algorithm compliancy with the testing protocol
	FOE-STD-1.0	Orientation extraction benchmark on fingerprints with orientation ground-truth manually labeled using an ad-hoc software tool. Good-quality and bad-quality datasets.

Current status

Registered Participants		127
	Academic Research Groups	21
	Companies	46
	Independent Developers	60



From July 2009
to February 2010

Algorithm Evaluated		388
	Fingerprint Verification	260
	Fingerprint ISO Template Matching	128
Results Published		20
	Fingerprint Verification	11
	Fingerprint ISO Template Matching	9

Protocols and results: on the web site

Benchmark protocols,
Published results,
Performance indicators,
Graphs,
...

The screenshot displays the FVC-onGoing website interface. At the top, the user is identified as 'Raffaele Cappelli' in the 'Public area'. The main content is titled 'Benchmarks' and includes a general introduction: 'FVC-onGoing provides various benchmarks to evaluate and compare recognition algorithms. Each benchmark is based on a sequestered dataset that will not evolve over time; in case new datasets will be added in the future, they will form a different benchmark (or a new version of an existing one). Only results obtained on the same data will be compared.' Below this, it states: 'Benchmarks are grouped into **Benchmark Areas** according to the (sub)problem addressed and the evaluation protocol adopted. In the following, the currently available benchmark areas and the corresponding benchmarks are briefly described.'

The interface features three benchmark areas, each with a descriptive text and a list of benchmarks:

- Fingerprint Verification**: This benchmark area contains fingerprint verification benchmarks. Fingerprint verification consists in comparing two fingerprints to determine whether they are impressions of the same finger or not (one-to-one comparisons). Algorithms submitted to these benchmarks are required to enroll fingerprints into proprietary or standard templates and to compare such templates to produce a similarity score. Read more...
Benchmarks: FV-STD-1.0, FV-TEST, FV-HARD-1.0
- Fingerprint Matching (ISO)**: This benchmark area contains fingerprint matching benchmarks using a standard minutiae-based template format [ISO/IEC 19794-2 (2005)]. Algorithms submitted to these benchmarks are required to compare ISO fingerprint templates to determine whether they are impressions of the same finger or not (one-to-one comparisons). No fingerprint enrollment (feature extraction) is required, only the minutiae matching algorithms are evaluated by these benchmarks. Read more...
Benchmarks: FMISO-STD-1.0, FMISO-TEST, FMISO-HARD-1.0
- Fingerprint Orientation Extraction**: The estimation of local fingerprint orientations is a fundamental step in fingerprint analysis and recognition (e.g., it is a prerequisite for image enhancement). This benchmark area contains benchmarks for local orientation extraction algorithms. Algorithms submitted to these benchmarks are required to extract local orientations from fingerprint images and to save them into a specific format. The extracted orientations are compared to the ground-truth in order to assess the algorithm accuracy. Read more...
Benchmarks: FOE-TEST, FOE-STD-1.0

The left sidebar contains navigation links: Home, Background, Benchmarks, Register, Published Results, Statistics, Participant area, Logout, Upload, Pending Algorithms, Tested Algorithms, Download, Past editions (FVC2006, FVC2004, FVC2002, FVC2000). The main content area also includes icons for '1-1 comparison', '1-1 ISO match', and 'Orient. Extraction'.








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







FVC-onGoing: on-line evaluation of fingerprint recognition algorithms

FV: Fingerprint Verification

- Benchmark FV-STD-1.0:






Published on	Benchmark	Participant	Type	Algorithm	Version	EER ▲	FMR1000	FMR10000	Show details
01/03/2010	FV-STD-1.0	Green Bit S.p.A	Company	GBFRSW	1.2.0.0	0,194%	0,274%	0,519%	
24/02/2010	FV-STD-1.0	AA Technology Ltd.	Company	EMB9200	2.1	0,216%	0,296%	0,440%	
25/11/2009	FV-STD-1.0	Green Bit S.p.A	Company	GBFRSW	1.0.0.0	0,261%	0,364%	0,487%	
20/07/2009	FV-STD-1.0	Neurotechnology	Company	MM_FV	3.0	0,281%	0,386%	0,581%	
31/08/2009	FV-STD-1.0	UnionCommunity	Company	Triple_M	1.0	0,665%	1,389%	2,403%	
15/07/2009	FV-STD-1.0	Secuest Inc.	Company	STAR	1.0	1,265%	2,504%	4,026%	
24/06/2009	FV-STD-1.0	jFinger Co., Ltd.	Company	JF_FV	V1.21a	1,618%	2,872%	4,545%	

- Benchmark FV-HARD-1.0:





Published on	Benchmark	Participant	Type	Algorithm	Version	EER ▲	FMR1000	FMR10000	Show details
24/02/2010	FV-HARD-1.0	AA Technology Ltd.	Company	EMB9200	2.1	0,824%	1,558%	2,376%	
01/03/2010	FV-HARD-1.0	Green Bit S.p.A	Company	GBFRSW	1.2.0.0	0,827%	1,667%	2,619%	
25/11/2009	FV-HARD-1.0	Green Bit S.p.A	Company	GBFRSW	1.0.0.0	1,046%	2,210%	3,152%	
20/07/2009	FV-HARD-1.0	Neurotechnology	Company	MM_FV	3.0	1,528%	3,043%	4,079%	

FMISO: Fingerprint ISO Template Matching

- Benchmark FMISO-STD-1.0:

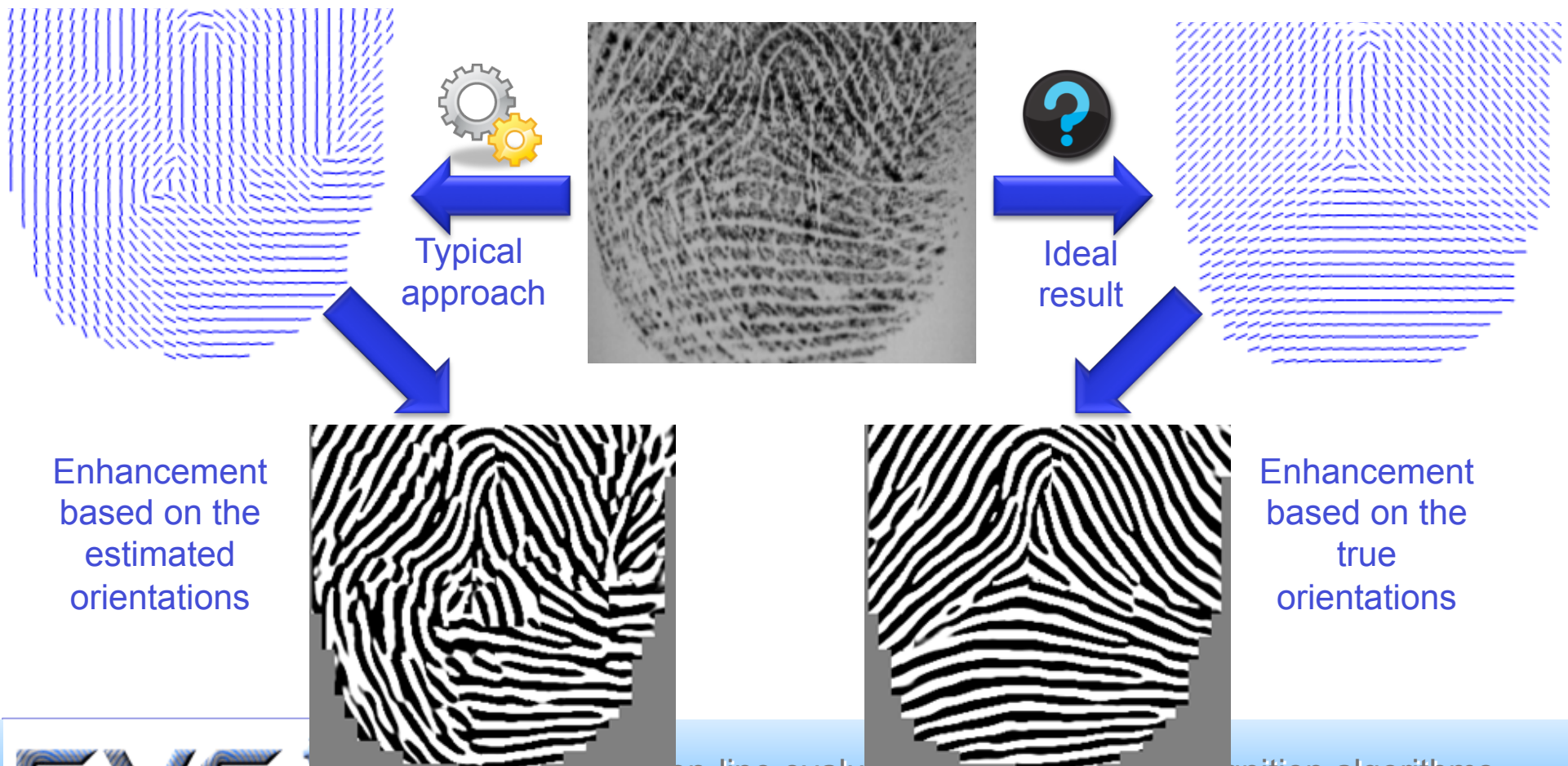
Published on	Benchmark	Participant	Type	Algorithm	Version	EER ▲	FMR1000	FMR10000	Show details
12/10/2009	FMISO-STD-1.0	Tiger IT Bangladesh	Company	Tiger ISO	0.1	0,317%	0,447%	0,866%	
09/09/2009	FMISO-STD-1.0	UnionCommunity	Company	Triple_M_ISO	1.0	0,405%	0,610%	1,064%	
26/02/2010	FMISO-STD-1.0	AA Technology Ltd.	Company	EMB9200	2.1	0,432%	0,570%	0,880%	
26/09/2009	FMISO-STD-1.0	APRO TECHNOLOGY (BANGKOK) CO., LTD.	Company	APF_FMISO	1.1	0,582%	0,801%	1,057%	
20/07/2009	FMISO-STD-1.0	Neurotechnology	Company	MM_FMISO	3.0	0,598%	0,801%	1,234%	

- Benchmark FMISO-HARD-1.0:

Published on	Benchmark	Participant	Type	Algorithm	Version	EER ▲	FMR1000	FMR10000	Show details
26/02/2010	FMISO-HARD-1.0	AA Technology Ltd.	Company	EMB9200	2.1	1,700%	3,002%	4,545%	
09/02/2010	FMISO-HARD-1.0	UnionCommunity	Company	Triple_M_ISO	v1.1	1,927%	3,908%	5,280%	
20/07/2009	FMISO-HARD-1.0	Neurotechnology	Company	MM_FMISO	3.0	2,430%	4,607%	6,139%	
26/09/2009	FMISO-HARD-1.0	APRO TECHNOLOGY (BANGKOK) CO., LTD.	Company	APF_FMISO	1.1	2,552%	4,581%	5,963%	

New Benchmark: Fingerprint Orientation Extraction

- Challenge: Estimation of local orientations in low-quality images
 - A fundamental step in fingerprint analysis and recognition

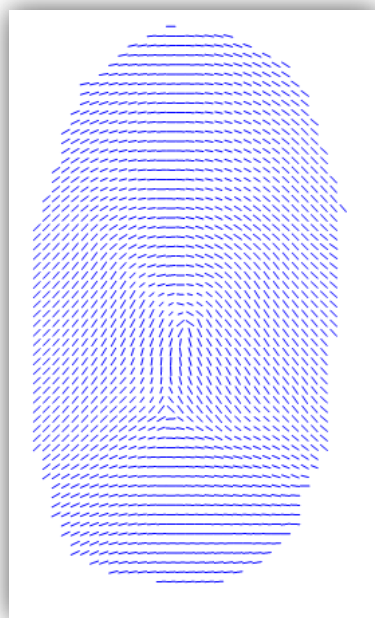


Evaluating Fingerprint Orientation Extraction

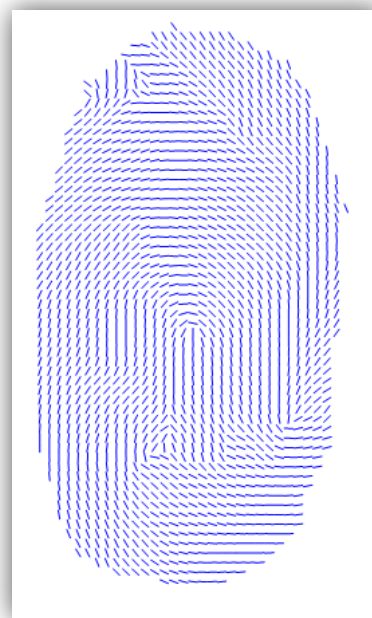
- How the benchmark works:
 - Participants' algorithms are required to extract local orientations from fingerprint images and to save them into a specific format.
 - The extracted orientations are compared to the **ground-truth** in order to assess the algorithm accuracy.



Fingerprint



Ground truth

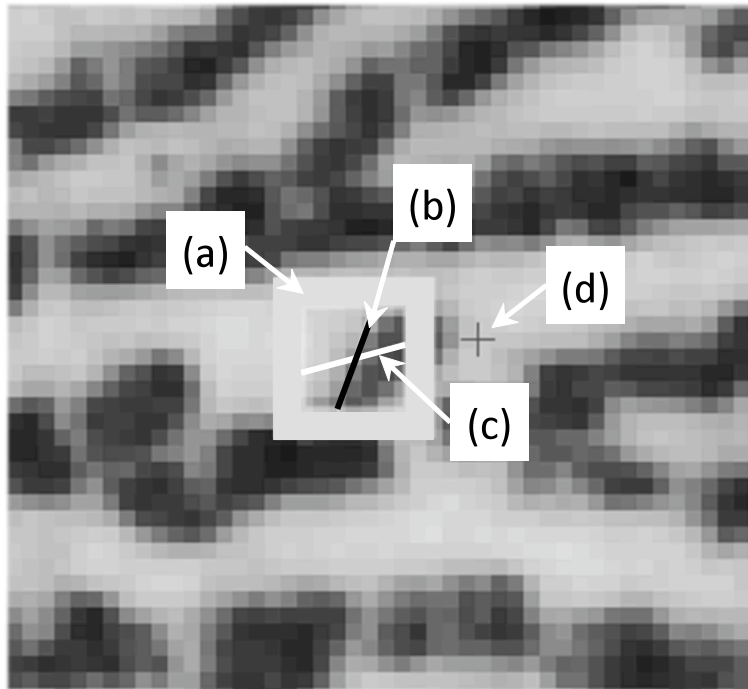


Extracted

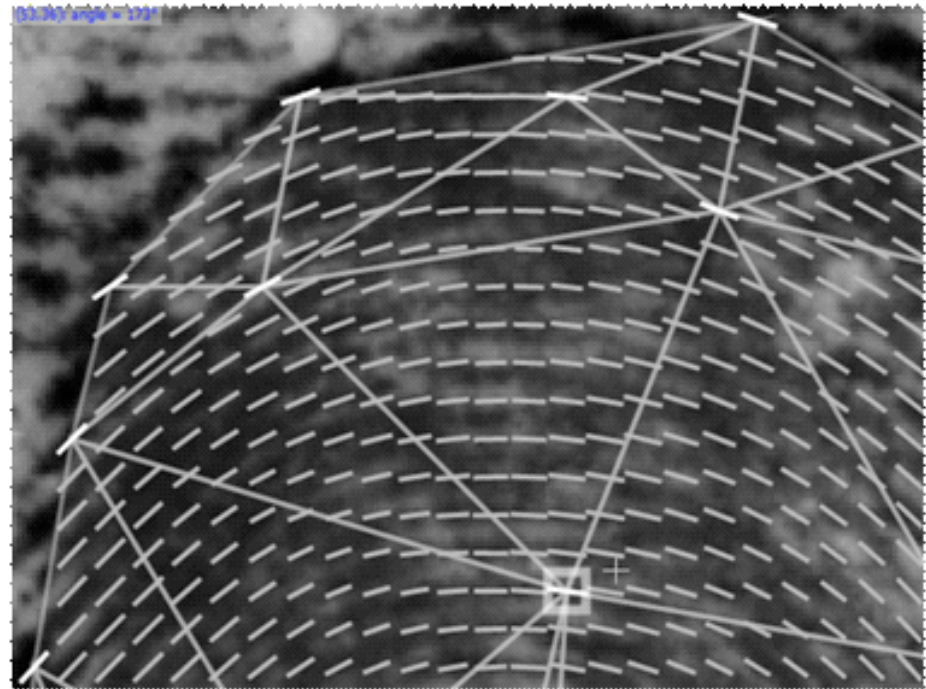


Errors

Software tool for orientation ground truth markup

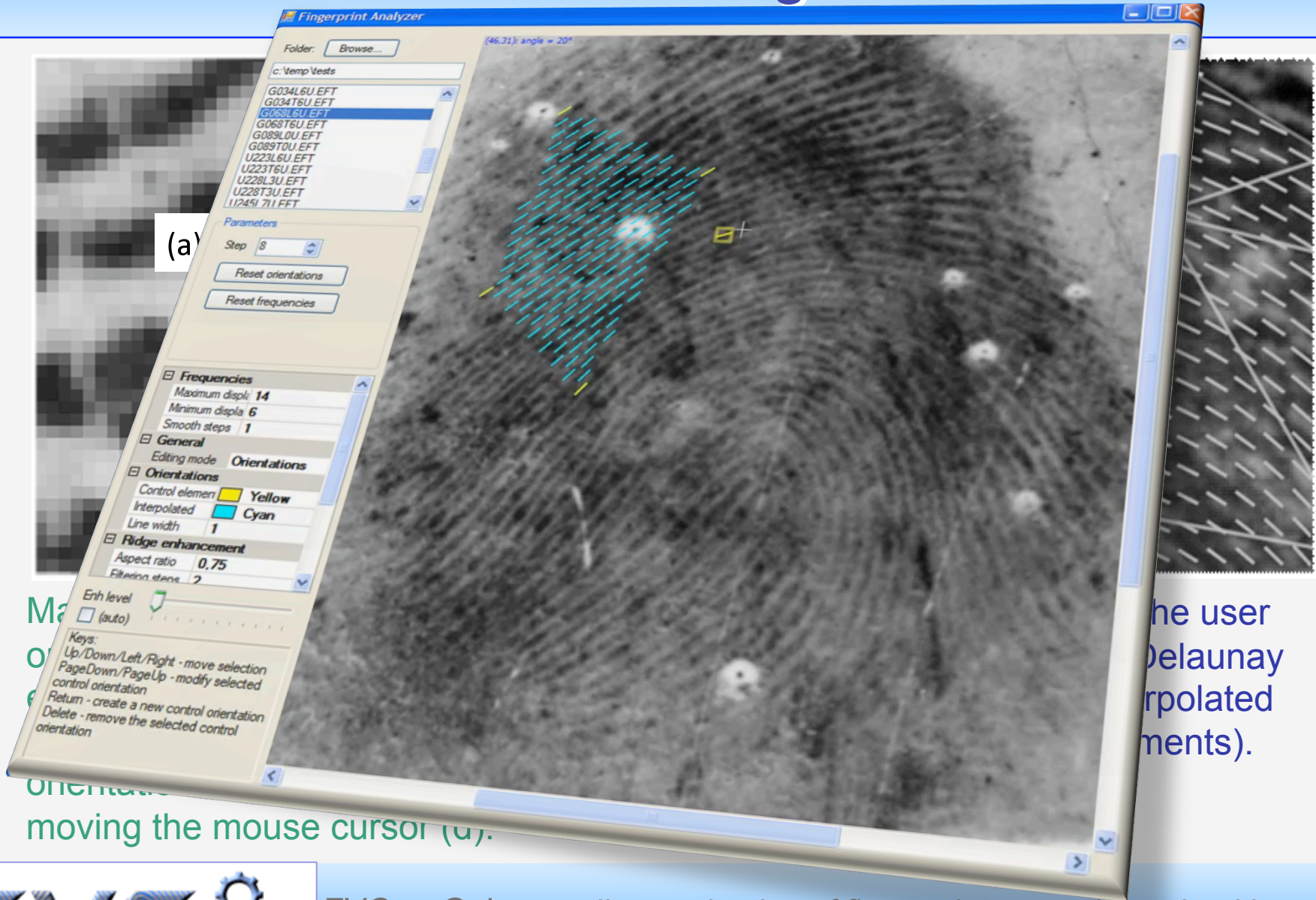


Manual adjustment of a single local orientation element: (a) the selected element, (b) the initial orientation proposed by the software, (c) the orientation selected by the user moving the mouse cursor (d).



Local estimations made by the user (white segments), with the Delaunay triangulation and all the interpolated local orientations (grey segments).

Software tool for orientation ground truth markup



the user
Delaunay
interpolated
elements).

ORIENTATIONS
moving the mouse cursor (a).

FOE: Datasets and Performance Indicators

- Datasets:

- The benchmarks consists of 2 datasets: a good quality dataset and a bad quality dataset.
- The challenge is to obtain a good orientation extraction accuracy on the bad quality dataset without losing too much accuracy on the good quality dataset.

- To reduce noise on low quality fingerprints, some approaches tend to oversmooth the orientation image and this could compromise accuracy on good quality fingerprints.

- Performance indicators:

- AvgErr_{BQ} (Average Error on the Bad Quality Dataset)
- AvgErr_{GQ} (Average Error on the Good Quality Dataset)
- Average orientation extraction time, Maximum amount of memory allocated
- Orientation deviation histogram (over all the orientation elements)
- Average error histogram (over all the fingerprints)

FOE: Datasets and Performance Indicators

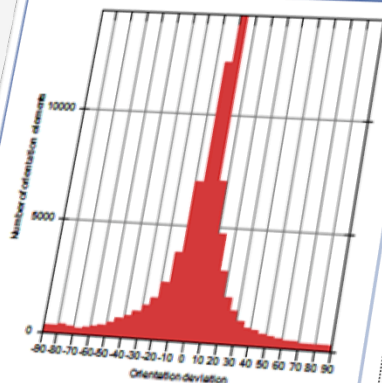
- Datasets:
 - The benchmarks consists of 2 datasets: a good quality dataset and a bad quality dataset.

Accuracy indicators	
AvgErr _{BQ}	AvgErr _{GQ}
22,91°	6,12°

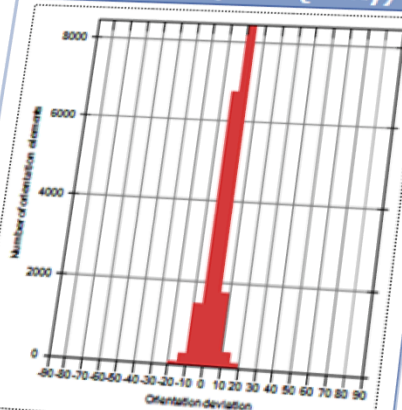
Efficiency and memory indicators	
Avg Extraction Time	Max Memory Allocated
77 ms	42604 KBytes

Graphs

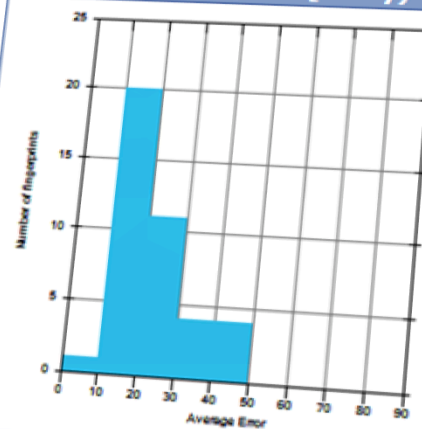
Orientation deviation distribution (Bad Quality)



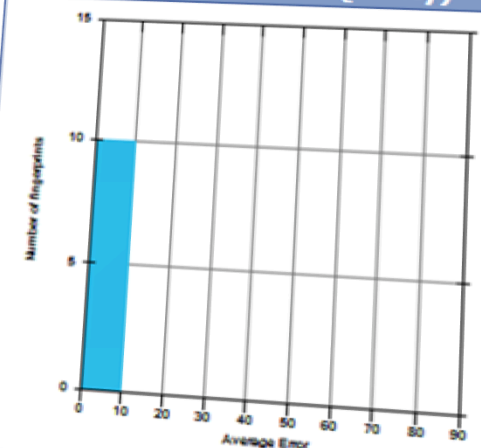
Orientation deviation distribution (Good Quality)



Average error distribution (Bad Quality)



Average error distribution (Good Quality)



FOE: Participant's toolkit and samples

- Source code: C and C# skeletons are available.
 - Perform all the necessary I/O (including loading image and foreground, saving the orientation image, ...).
- Sample datasets
- Sample algorithm (Gradient-based) and Test runner tool
- Software viewer to display:
 - Fingerprints,
 - Ground truth,
 - Orientations extracted by an algorithm,
 - Orientation differences (errors)



FOE: Participant's toolkit and samples

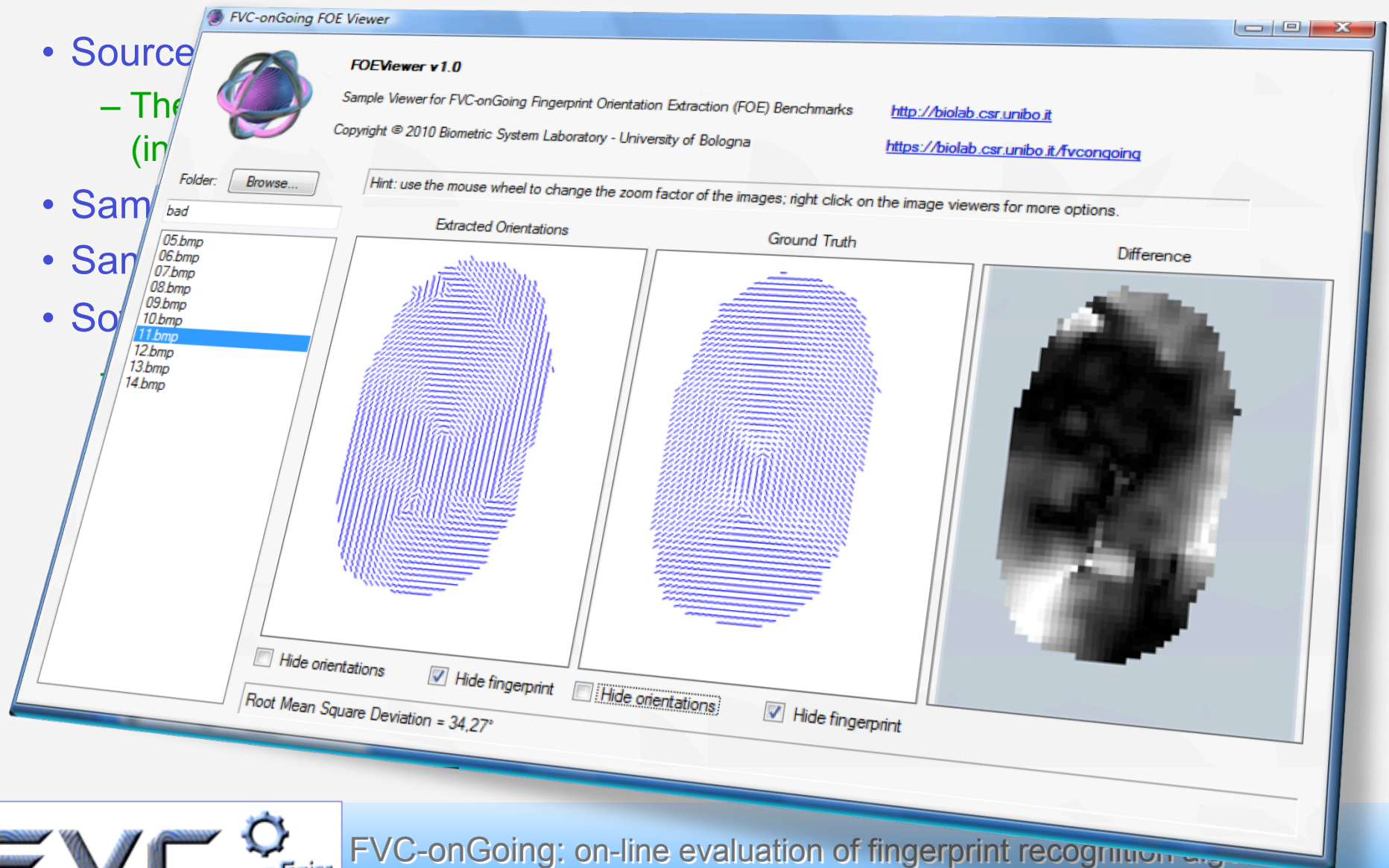
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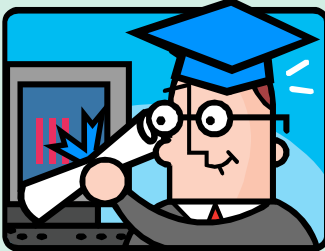
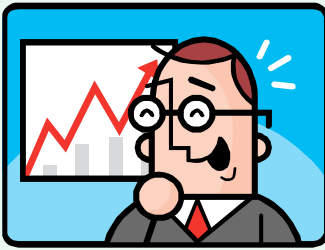
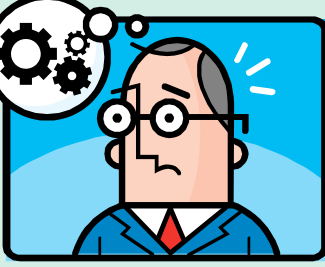
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- Sam

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FVC-onGoing: for Whom?

Who	Why
 <p>Researcher Reviewer</p>	<ul style="list-style-type: none">• New algorithms can be easily compared to the state-of-the-art.• Benchmarks not only for the whole recognition problem, but also for sub-problems.
 <p>Vendor Developer</p>	<ul style="list-style-type: none">• FVC-onGoing is an evolving online repository of evaluation metrics and results.• Participants can see the results before publishing.• The competition is always open: new algorithms and new versions can be submitted at any time.
 <p>End user Sys. Integrator</p>	<ul style="list-style-type: none">• At any time, end users and system integrators may ask potential providers to assess their performance on one or more benchmarks.• An evolving snapshot of the fingerprint recognition technology.



The next steps

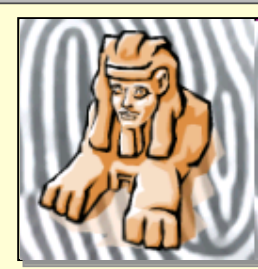
- New benchmark areas planned
 - Fingerprint Indexing
 - Fingerprint Identification (1:N)
 - Minutiae extraction accuracy



- New benchmarks with synthetic datasets
 - Large datasets for Fingerprint Orientation Extraction (orientation ground-truth can be automatically generated by SFinGe)
 - Datasets for Minutiae Extraction Accuracy (minutiae ground-truth automatically generated by SFinGe)

SFinGe (the Italian for Sphinx, pron. *sphin-je*)

A software able to synthetically (randomly) generate large databases of realistic fingerprint images with ground truth data (minutiae, local orientations, ...)



Links

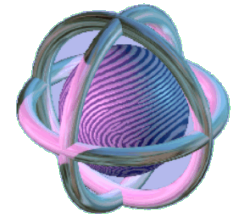
- FVC-onGoing web site:



🌐 <http://biolab.csr.unibo.it/FVConGoing>

🌐 ...or Google “fvc on going” and press “I’m Feeling Lucky”

- Biometric System Laboratory web site:




🌐 <http://biolab.csr.unibo.it>

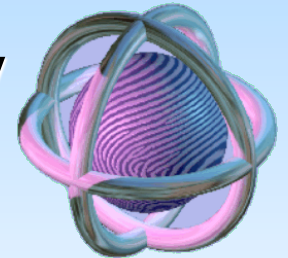
🌐 ...or Google “biometric system laboratory” and press “I’m Feeling Lucky”



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BioLab - Biometric System Laboratory
University of Bologna - ITALY 

<http://biolab.csr.unibo.it>



Thank you !



Benchmark Area Fingerprint Verification (FV)

- Benchmarks:

- FV-TEST: A simple dataset useful to test algorithm compliancy with the testing protocol.
 - Results cannot be published.
- FV-STD-1.0: Fingerprint images acquired in operational conditions using high-quality optical scanners.
 - Results should reflect the expected accuracy in large-scale fingerprint-based applications.
- FV-HARD-1.0: Contains a relevant number of difficult cases (noisy images, distorted impressions, etc.) that makes fingerprint verification more challenging.
 - Results do not necessarily reflect the expected accuracy in real applications.



Benchmark	Scanner Type	Resolution	Minimum Image Size	Maximum Image Size	Genuine Attempts	Impostor Attempts
FV-TEST	Optical	500 dpi	440x500	440x500	280	45
FV-STD-1.0	Optical	500 dpi	440x500	440x500	27720	87990
FV-HARD-1.0	Optical	500 dpi	260x374	448x500	19320	20850

Fingerprint Verification (FV): Protocol

- From the FVC-onGoing web site:

Each participant is required to submit, for each algorithm, **two** executables in the form of Win32 console applications.

- Both executables will take the input from command-line arguments and will append the output to a text file.
- 1. The first executable (**enroll.exe**) enrolls a fingerprint image and produces a template file; the command-line syntax is:
`enroll.exe <imagefile> <templatefile> <outputfile>`
where:

imagefile	the input image pathname
templatefile	the output template pathname
outputfile	the output text-file, where a log string (of the form <code>imagefile templatefile result</code>) must be appended; result is "OK" if the enrollment can be performed or "FAIL" if the input image cannot be processed by the algorithm

2. The second executable (**match.exe**) matches two fingerprint templates and produces a similarity score; the command-line syntax is:
`match.exe <templatefile1> <templatefile2> <outputfile>`
where:

templatefile1	the first input template pathname
templatefile2	the second input template pathname
outputfile	the output text-file, where a log string (of the form <code>templatefile1 templatefile2 result similarity</code>) must be appended; result is "OK" if the matching can be performed or "FAIL" if the matching cannot be executed by the algorithm; similarity is a floating point value ranging from 0 to 1 which indicates the similarity between the two templates: 0 means no similarity, 1 maximum similarity

- **Both executables have to operate only on the explicitly-given inputs**, without exploiting any learning technique or template consolidation/update based on previous enrolls/matches.
- **C and C# language skeletons** for enroll.exe and match.exe are available in the [download page](#) to reduce the participants implementation efforts. These source files perform all the necessary I/O (including image loading).

Benchmark Area Fingerprint Matching ISO (FMISO)

- Benchmarks:

- FMISO-TEST: A simple dataset useful to test algorithm compliancy with the testing protocol
 - Results obtained on this benchmark cannot be published.
- FMISO-STD-1.0: ISO templates created from fingerprint images acquired in operational conditions using high-quality optical scanners.
 - Results should reflect the expected accuracy in large-scale fingerprint-based applications.
- FMISO-HARD-1.0: Contains a relevant number of difficult cases (noisy images, distorted impressions, etc.).
 - Results do not necessarily reflect the expected accuracy in a real applications.



Benchmark	Scanner Type	Resolution	Minimum Template Size	Maximum Template Size	Genuine Attempts	Impostor Attempts
FMISO-TEST	Optical	500 dpi	440x500	440x500	280	45
FMISO-STD-1.0	Optical	500 dpi	440x500	440x500	27720	87990
FMISO-HARD-1.0	Optical	500 dpi	260x374	448x500	19320	20850

Fingerprint Matching ISO (FMISO): Protocol

- From the FVC-onGoing web site:

Protocol

Each participant is required to submit, for each algorithm, an executable in the form of Win32 console application.

- The executable (**match.exe**) will take the input from command-line arguments and will append the output to a text file. It matches two ISO templates and produces a similarity score; the command-line syntax is:

```
match.exe <ISOtemplatefile1> <ISOtemplatefile2> <outputfile>
```

where:

ISOtemplatefile1	the first input ISO template pathname
ISOtemplatefile2	the second input ISO template pathname
outputfile	the output text-file, where a log string (of the form ISOtemplatefile1 ISOtemplatefile2 result similarity) must be appended; result is "OK" if the matching can be performed or "FAIL" if the matching cannot be executed by the algorithm; similarity is a floating point value ranging from 0 to 1 which indicates the similarity between the two templates: 0 means no similarity, 1 maximum similarity

- **The executable has to operate only on the explicitly-given inputs**, without exploiting any learning technique or template consolidation/update based on previous enrolls/matches.
- **C and C# language skeletons** for match.exe are available in the [download page](#) to reduce the participants implementation efforts. These source files perform all the necessary I/O (including ISO template loading).