INTERNATIONAL STANDARD

ISO/IEC 29159-1

First edition
2010-09-01

Information technology — Biometric calibration, augmentation and fusion data —

Part 1:
Fusion information format

Technologies de l'information — Étalonnage biométrique, données d'augmentation et de fusion —

Partie 1: Format d'information de fusion

Reference number
ISO/IEC 29159-1:2010(E)

ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

Published in Switzerland

Contents

Page

Foreword v
Introduction vi
1 Scope 1
2 Conformance 1
3 Normative references 1
4 Terms and definitions 1
5 Symbols and abbreviated terms 2
6 Fusion information format (FIF) 3
6.1 Overview 3
6.2 Byte ordering 4
6.3 Numeric values 4
6.4 Fusion header block 4
7 Common elements 8
7.1 General 8
7.2 Parameter kind 8
7.3 Parameter origin 9
7.4 Distributions present 9
7.5 Number of comparisons 9
7.6 Pre-normalization flag 9
8 Type 1 record 10
8.1 Purpose 10
8.2 Format 10
8.3 Use case (Informative) 11
9 Type 2 record 12
9.1 Purpose 12
9.2 Format 12
9.3 Use case (Informative) 13
10 Type 3 record 13
10.1 Purpose 13
10.2 Format 14
Annex A (informative) Document Overview 16
Annex B (informative) Example Cumulative Distribution Functions 18
Annex C (informative) Use of pre-normalized data 20
Annex D (informative) Source for evaluation of spline 22
Bibliography 23

Figures

Figure 1 — Schematic representation of fusion information format usage vii
Figure B.1 — Example CDFs and their spline representations 19
Figure C.1 — Example CDFs of internal comparison scores and pre-normalized scores 20

Tables

Table 1 — Fusion information format record structure ... 3
Table 2 — Fusion header block structure ... 3
Table 3 — Type 1 record structure ... 3
Table 4 — Type 2 record structure ... 4
Table 5 — Type 3 record structure ... 4
Table 6 — Textual representation of numerical value ... 4
Table 7 — The fusion header block ... 5
Table 8 — CBEFF Product Identifiers ... 6
Table 9 — Database identifiers ... 6
Table 10 — Database quality values ... 7
Table 11 — Score sense codes ... 8
Table 12 — Identifiers for statistical quantities ... 8
Table 13 — Origins of statistical data ... 9
Table 14 — Distribution information present ... 9
Table 15 — Pre-normalization codes ... 10
Table 16 — Subtype A format ... 10
Table 17 — Type 1 record format ... 10
Table 18 — Subtype B format ... 12
Table 19 — Type 2 record format ... 12
Table 20 — Subtype C format ... 14
Table 21 — Type 3 record format ... 14
Table A.1 — Fusion information format type taxonomy ... 16

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/IEC 29159-1 was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee SC 37, *Biometrics*.

ISO/IEC 29159 consists of the following parts, under the general title *Information technology — Biometric calibration, augmentation and fusion data*:

— *Fusion information format*

Introduction

Biometric systems embed disparate technologies and comparison algorithms. Although some of these have been published, most are entirely proprietary. Most current verification or identification applications employ a single biometric modality. That is, information is acquired from a body part or an exhibited behavior with the intent of more or less uniquely identifying the individual. For example, an access control system can image the hand and use geometrical features. A social benefits program can collect fingerprints from applicants as input to a one-to-many duplicate search. Different biometric modes offer varying amounts of discriminative information and have different acquisition related problems. The effect is that biometric systems are to some extent fallible and, moreover, they exhibit different failure modes. This affords opportunities to combine technologies or algorithms to improve performance and/or usability. Such combination is known as fusion. Fusion can be multi-modal (e.g. observing the biometric characteristics, face and finger), multi-algorithmic (e.g. face recognition algorithms A and B), multi-instance (e.g. index finger and thumb), multi-sensorial (e.g. optical and ultrasound fingerprint sensor) or multi-presentation (e.g. three images of a user's face).

This part of ISO/IEC 29159 addresses the most common and most readily implemented method of fusion: score-level fusion. This is implemented after two or more systems have processed and matched an individual's biometric information to one or more enrolled samples and produced scalar comparison scores as output. The scores can be either genuine (same-person) or impostor (different-person) scores and a fusion scheme is designed to combine such scores so that the class boundary between genuine and impostor scores is refined.

Distributions of comparison scores are unique to each biometric comparison subsystem. Score ranges and the shapes of the distributions can differ greatly. Fusion is often implemented in two ways.

— In classification-based processes, the available comparison scores are combined directly to produce an output decision or score.

— In normalization-based processes, fusion is preceded by a transformation of each score to a common domain. Simple normalization techniques based on statistical parameters such as the mean and standard deviation are sometimes effective, but more sophisticated techniques utilize detailed knowledge of the entire score distribution. The fusion information format (FIF) defined in this part of ISO/IEC 29159 is intended to flexibly support any of the popular transformations. By establishing a standardized means of data exchange, this part of ISO/IEC 29159 supports a modular approach to biometric systems integration in which both the comparison and fusion algorithms remain protected as black-box pieces of intellectual property. Thus this part of ISO/IEC 29159 envisages an application in which two (or more) underlying acquisition and comparison technologies (hand geometry and fingerprint, for example) each generate a score which is fed to a fusion module which has been initialized with an appropriate instance of the FIF defined herein.

Figure 1 depicts the logical role of the records in a (notional) multimodal fusion process.

This part of ISO/IEC 29159 defines containers for the distributional score information from a comparison subsystem. It does not allow for joint distributional data that can fully capture the statistical properties of multivariate scores (i.e. those from two or more vendors' subsystems or modalities). This means that multimodal fusion is not supported by a description of the joint distributions of the biometric scores. This is often a minor limitation because different modalities are often assumed to be independent. Even when the scores are not independent, as is the case for multi-algorithm applications, score-level fusion techniques often remain effective, even if they are not optimal.

This part of ISO/IEC 29159 is intended to support interoperability and data interchange among biometrics applications and systems. As such it specifies requirements that solve the complexities of applying biometrics to a wide variety of personal recognition applications, whether such applications operate in an open systems environment or consist of a single, closed system. Open systems are built on standards based, publicly defined data formats, interfaces, and protocols to facilitate data interchange and interoperability with other systems, which can include components of different design or manufacture. A closed system can also be built on publicly defined standards, and can include components of different design or manufacture, but inherently has no requirement for data interchange and interoperability with any other system.

Biometric data interchange format standards and biometric interface standards are both necessary to achieve full data interchange and interoperability for biometric recognition in an open systems environment. The biometric International Standards developed within JTC 1/SC 37 form a layered set of International Standards consisting of biometric data interchange formats and biometric interfaces, as well as application profiles that describe the use of these International Standards in specific application areas.

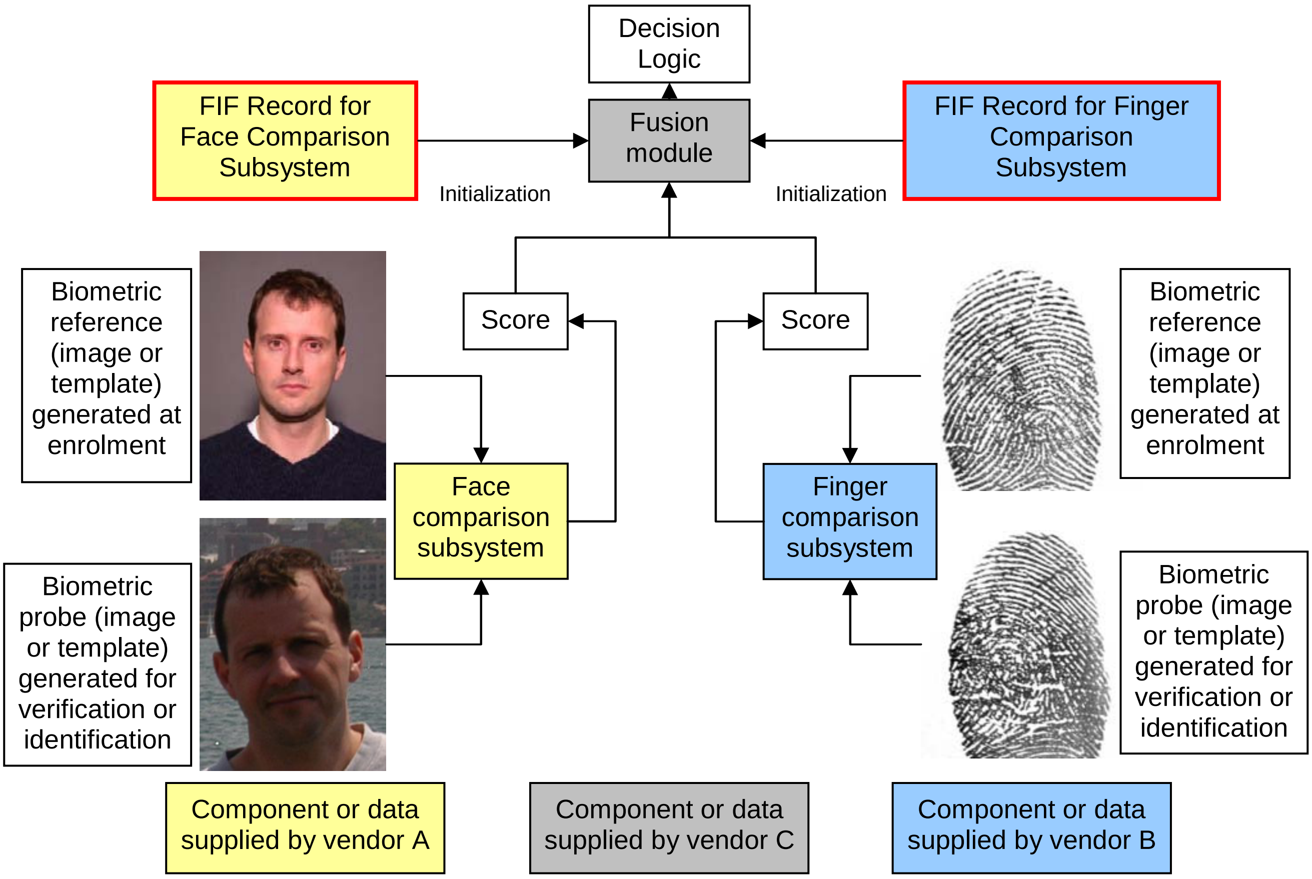


Figure 1 — Schematic representation of fusion information format usage

Information technology — Biometric calibration, augmentation and fusion data —

Part 1:
Fusion information format

1 Scope

This part of ISO/IEC 29159 specifies a biometric fusion information format that establishes machine readable data formats to describe the statistics of comparison score inputs to a fusion process.

This part of ISO/IEC 29159 does not

— standardize comparison-score normalization processes, nor

— standardize or define fusion processes.

2 Conformance

Records are conformant to this part of ISO/IEC 29159 if they conform to all normative requirements of Clause 6. This requires conformance to either Clause 8, 9, or 10, each of which requires conformance to the stated subclauses of Clause 7.

3 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEEE 754-2008, *IEEE Standard for Floating-Point Arithmetic*

ISO/IEC 19785-1:2006, *Information technology — Common Biometric Exchange Formats Framework — Part 1: Data element specification*

ISO/IEC 19794-1:2006, *Information technology — Biometric data interchange formats — Part 1: Framework*

4 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC 19794-1 and the following apply.

4.1
biometric sample
analog or digital representation of biometric characteristics prior to biometric feature extraction

NOTE A biometric capture device is a biometric capture subsystem with a single component.

4.2
cumulative distribution function
probability that a variate takes on a value less than or equal to a number

4.3
genuine score
comparison score from comparison of two samples from one person

4.4
impostor score
comparison score from comparison of two samples from different persons

4.5
location parameter
generic measure of the position of a distribution

NOTE The location parameter is not necessarily the mean of a distribution.

4.6
probability density function
derivative of the cumulative distribution function

4.7
scale parameter
generic measure of the breadth of a distribution

NOTE The scale parameter is generally not the variance (nor the standard deviation) of a distribution.

4.8
comparison score
scalar output from biometric comparison subsystem

NOTE The term comparison score is used generically in this part of ISO/IEC 29159 for both distances (smaller indicates greater likelihood that samples come from same person) and similarity scores (higher indicates same-person). This distinction is conveyed explicitly in the score sense type defined in 6.4.9.

5 Symbols and abbreviated terms

For the purposes of this document, the following abbreviations apply. In tables that define binary record structures the use of the symbol "M" in the status column indicates that the field itself is mandatory. A value of "O" indicates the field is optional. This means that the bytes for the fields might not be present. In all cases records can be parsed because the presence or absence of an optional field is recorded in a preceding field.

CBEFF Common Biometric Exchange Formats Framework

CDF cumulative distribution function

ECDF empirical cumulative distribution function

FAR false accept rate

FMR false match rate

FIF fusion information format

PDF probability density function

ID identifier

6 Fusion information format (FIF)

6.1 Overview

6.1.1 Record structure

The FIF record is used to support modularity in multi-modal biometric and decision support systems. Its format is given in Table 1.

NOTE An application should establish a profile of part of the ISO/IEC 29159 standard. A default profile would explicitly call out one of the record types.

Table 1 — Fusion information format record structure

Fusion header block	Type 1 Record (see clause 6.1.3)	and/or	Type 2 Record (see clause 6.1.4)	and/or	Type 3 Record (see clause 6.1.5)

6.1.2 Header structure

The fusion header block structure defines the format of the record, and indicates the content. Its format is given in Table 2.

Table 2 — Fusion header block structure

Fusion header block	=	Format Identifier	Version Number	Record Length	Biometric Type
clause 6.4		6.4.2	6.4.3	6.4.4	6.4.5
25 bytes		4	4	4	3

row continuation	Comparison Subsystem Product ID	Database ID	Enrolment Database quality	Verification Database quality	Score Sense	Number of Type Instances
	6.4.6	6.4.7	6.4.8	6.4.8	6.4.9	6.4.10
	4	2	1	1	1	1

6.1.3 Type 1 record structure

The fusion header block structure defines the format of the record, and indicates the content. Its format is given in Table 3.

Table 3 — Type 1 record structure

Type 1 Record Structure	=	Type	Distributions Present	Impostor Distribution			Genuine Distribution		
				Num Comp	Loc	Scale	Num Comp	Loc	Scale
clause 8.2		8.2.3	8.2.4	8.2.5	8.2.6	8.2.7	8.2.8	8.2.9	8.2.10
26 or 50 bytes		1	1	4	10	10	4	10	10

6.1.4 Type 2 record structure

The fusion header block structure defines the format of the record, and indicates the content. Its format is given in Table 4.

Table 4 — Type 2 record structure

Type 2 Record Structure	=	Type	Distributions Present	Impostor Distribution CDF	Genuine Distribution CDF
clause 9.2		9.2.3	9.2.4	9.2.5	9.2.6
16N+13 or 32N+22 bytes		1	1	16N+11	16N+11

6.1.5 Type 3 record structure

The fusion header block structure defines the format of the record, and indicates the content. Its format is given in Table 5.

Table 5 — Type 3 record structure

Type 3 Record Structure	=	Type	Distributions Present	Impostor Distribution CDF	Genuine Distribution CDF
clause 10.2		10.2.3	10.2.4	10.2.5	10.2.6
16N-18 or 32N-38 bytes		1	1	16N-20	16N-20

6.2 Byte ordering

Within the FIF record, and all well-defined data blocks therein, all multi-byte quantities shall be stored in Big Endian format. That is, the more significant bytes of any multi-byte quantity are stored at lower addresses in memory than the less significant bytes.

EXAMPLE For example, the value 1025 (2 to the 10th power plus one) would be stored as first byte= 00000100b and second byte=00000001b.

6.3 Numeric values

All numeric values present in the defined Types of this part of ISO/IEC 29159 are fixed-length unsigned integer quantities, unless specified otherwise.

All numeric values given in the text of this part of ISO/IEC 29159 are decimals, unless preceded by 0x, to indicate hexadecimal, or suffixed by a "b" to indicate binary.

Table 6 — Textual representation of numerical value

Example value	Radix	Decimal value
1010b	2	10
39	10	39
0xF5	16	245

Double precision numbers shall be conformant with IEEE 754.

NOTE The specification of IEEE 754 may not be sufficient to avoid numerical inaccuracy.

6.4 Fusion header block

6.4.1 General

The fusion header block of Table 7 shall be present as the first block in all FIF records.

Table 7 — The fusion header block

Field	Status	Size (bytes)	Valid Values	Notes
Format identifier	M	4	0x46494600	ASCII string "FIF" with null terminator
Version number	M	4	0x30313000	ASCII string "010" with null terminator
Record length	M	4	$1 \le L \le 2^{32} -1$	Length of entire record in bytes
Biometric type	M	3	$0 \le t \le$ 0x080000	The modality from which this record came from
Comparison subsystem product ID	M	4	≥ 0	Currently vendor specified ID.
Database ID	M	2	≥ 0	Currently vendor specified ID.
Enrollment sample quality	M	1	[0-100],254,255	Aggregate qualities of the samples used to compute the comparison score statistics
Verification sample quality	M	1	[0-100],254,255	
Score sense	M	1	0 or 1	Distances or similarities? See clause 6.4.9.
Number of type instances	M	1	$1 \le N \le 4$	0 is not allowed

6.4.2 Format identifier

The (4-byte) format identifier shall begin with the three ASCII characters ‘FIF’ to identify the record as following this part of ISO/IEC 29159, followed by a zero byte as a null string terminator.

6.4.3 Version number

The (4-byte) version number shall consist of three ASCII numerals followed by a zero byte as a NULL string terminator. The value denotes the version of this part of ISO/IEC 29159.

The first and second character represents the major version number and the third character represents the minor revision number.

The version number shall be 0x30313000 which is “010” – Version 1 revision 0.

6.4.4 Record length

The (4-byte) record length block shall be the combined length in bytes for the entire record. It shall be the sum of the fusion header block length (25 bytes) and any Type 1, 2 or 3 record lengths that follow.

6.4.5 Biometric type

The (3-byte) value shall be taken from CBEFF's enumeration of biometric modalities given in ISO/IEC 19785-1:2005, 6.5.6. This value allows an application to know what biometric modality is represented by the instance of the fusion information format.

EXAMPLE For scores from an implementation using vein patterns this value would be 0x040000.

6.4.6 Comparison subsystem Product ID

The (4-bytes = 2 + 2 bytes) identifier of the comparison subsystem algorithm (i.e. comparing the biometric probe with the biometric reference) that produced the scores information described in this FIF record shall be recorded according to Table 8. These two values are the CBEFF Product Identifiers described in ISO/IEC 19785-1:2006.

Table 8 — CBEFF Product Identifiers

	Assigned by	Length	Description
Product ID (stored in the first two bytes)	IBIA	2 bytes	See ISO/IEC 19785-1:2006
Version Number (stored in the second two bytes)	Vendor	2 bytes	

NOTE 1 It can be argued that a Product ID field is not needed because the statistical information embodies all that is needed by a fusion module. The field is however useful to support, for example, version control and caching.

NOTE 2 The Product ID alone is likely insufficient to execute score normalization. It may nevertheless be useful to applications using the records of this part of ISO/IEC 29159.

6.4.7 Database ID

The (2-byte) vendor-specified identifier of the database used by the vendor's comparison subsystem in creation of the scores used in the computation of the data contained in fields 4 and 5 shall be recorded according to Table 9. This field might be used

— by a comparison subsystem provider to arbitrarily indicate what data they used in computing the FIF record contents, or

— in an application profile or requirements document to firmly specify that suppliers must use a specific entry (for example item 49, the MINEX POEBVA fingerprint calibration database).

NOTE ISO/IEC JTC 1 SC 37 maintains a process for registration of other databases for use in generating ISO/IEC 29159-1 records. The Registry of Database IDs includes the databases listed below.

Table 9 — Database identifiers

Dataset ID	Distribution	Modality
0	Unspecified	
1	Unknown	
2	Composite	
3-15	Reserved	
16.	FERET Face Database http://www.itl.nist.gov/iad/humanid/colorferet/	Face
17.	Yale Face Database http://cvc.yale.edu/projects/yalefaces/yalefaces.html	Face
18.	PIE Database CMU http://www.ri.cmu.edu/projects/project_418.html	Face
19.	AR Database http://cobweb.ecn.purdue.edu/~aleix/aleix_face_DB.html	Face
20.	FRGC I Database http://face.nist.gov/frvt/	Face
21.	FRGC II Database http://face.nist.gov/frvt/	Face
22.	FRVT 2002 HCInt (i.e. FRVT 2006 Low Resolution) Database http://face.nist.gov/frvt/	Face
23.	FRVT 2006 High Resolution Database http://face.nist.gov/frvt/	Face
24.	FRVT 2006 Very High Resolution Database http://face.nist.gov/frvt/	Face
25.	FVC 2000	Finger
26.	FVC 2002 DB1 http://bias.csr.unibo.it/fvc2002/	Finger
27.	FVC 2002 DB2 http://bias.csr.unibo.it/fvc2002/	Finger
28.	FVC 2002 DB3 http://bias.csr.unibo.it/fvc2002/	Finger
29.	FVC 2002 DB4 (synthetic) http://bias.csr.unibo.it/fvc2002/	Finger
30.	FVC 2004 DB1 http://bias.csr.unibo.it/fvc2004/	Finger
31.	FVC 2004 DB2 http://bias.csr.unibo.it/fvc2004/	Finger
32.	FVC 2004 DB3 http://bias.csr.unibo.it/fvc2004/	Finger
33.	FVC 2004 DB4 (synthetic) http://bias.csr.unibo.it/fvc2004/	Finger
34.	FVC 2006 DB1 http://bias.csr.unibo.it/fvc2006/	Finger
35.	FVC 2006 DB2 http://bias.csr.unibo.it/fvc2006/	Finger
36.	FVC 2006 DB3 http://bias.csr.unibo.it/fvc2006/	Finger

Dataset ID	Distribution	Modality
37.	FVC 2006 DB4 (synthetic) http://bias.csr.unibo.it/fvc2006/	Finger
38.	NIST Special Database 27 http://fingerprint.nist.gov	Latent finger
39.	NIST Special Database 29 http://fingerprint.nist.gov	Finger
40.	MCYT Fingerprint subcorpus http://atvs.ii.uam.es/bbdd_EN.html	Finger
41.	MCYT Signature subcorpus http://atvs.ii.uam.es/bbdd_EN.html	Signature
42.	BANCA still http://www.ee.surrey.ac.uk/banca/	Face
43.	BANCA video http://www.ee.surrey.ac.uk/banca/	Voice
44.	BANCA high quality http://www.ee.surrey.ac.uk/banca/	Voice
45.	BANCA low quality http://www.ee.surrey.ac.uk/banca/	Voice
46.	NIST Speaker Verification http://www.nist.gov/speech/tests/spk/2005/	Voice
47.	NIST Speaker Verification http://www.nist.gov/speech/tests/spk/2006/	Voice
48.	CASIA Iris http://www.nlpr.ia.ac.cn/english/irds/irisdatabase.htm	Iris
49.	Bath Iris http://www.irisbase.com	Iris
50.	ICE 2005 http://iris.nist.gov/ice/	Iris
51.	ICE 2006 http://iris.nist.gov/ice/	Iris
52.	NIST MINEX DHS2 calibration set http://fingerprint.nist.gov	Finger
53.	NIST MINEX POE calibration set http://fingerprint.nist.gov	Finger
54.	NIST MINEX DOS calibration set http://fingerprint.nist.gov	Finger
55.	NIST MINEX POEBVA calibration set http://fingerprint.nist.gov	Finger
56.	TURBINE GUC100 http://www.nislab.no/guc100	Finger
57.-2047	Reserved	
2048 - 65535	Vendor assigned, possibly non-public and non-unique across vendors	

NOTE 1 Although some of these databases are not available to the public they are listed here to support future calibration efforts.

NOTE 2 Although some of these databases are not freely available, they are listed here to point out their existence to users of this part of ISO/IEC 29159.

NOTE 3 The performance of fusion systems will have some sensitivity to the databases used. This is because the comparison score distributions obtained by matching samples from one database will generally be different than from another. See Annex C for a discussion of the stability of distributions.

6.4.8 Database quality

The qualities of the samples in a database may have been aggregated together to form a scalar database quality value. Two (1-byte) quality summary values shall be stored in consecutive fields, the first for the reference samples, the second for the probe samples. A value of 0 shall represent the lowest possible quality and the value 100 shall represent the higher possible quality. For each field, the allowed values are given in Table 10.

Table 10 — Database quality values

Value	Meaning
0 - 100	Assigned value
254	Unassigned because no attempt was made to compute value
255	Unassigned because of failed attempt to assign a quality score

6.4.9 Score sense

The raw outputs from biometric comparison subsystems may be either distances or similarities. Small values for distances indicate greater likelihood that the score is a genuine score; for similarities, higher values indicate this. A 1 byte field with values allowed by Table 11 shall be used to record score sense.

Table 11 — Score sense codes

Sense	Value (1 byte)
Distance	0
Similarity	1

NOTE The use of the word distance does not necessarily imply that values have the metric property.

6.4.10 Number of type instances

The (1-byte) number of type instances block shall be the number of Type 1, 2, or 3 records included in the FIF record. A record shall contain zero or one instance of each Type, but there shall always be one instance of one of them. Thus the number of type instances shall be on 1, 2 or 3.

EXAMPLE If both a Type 1 and Type 3 instance are present, this value will be 2.

NOTE An application profile (or equivalent specification) might appropriately call-out one specific type.

7 Common elements

7.1 General

This clause defines generic data structures to support the Type 1, 2 and 3 records of this part of ISO/IEC 29159. This clause also includes tables that enumerate values and associates them with their respective meanings.

Note that in some tables the first column is entitled "Field" and contains a numeric entry. These are included only for ease of reference to the rows – the values should not be included in instances of the standard's binary records.

7.2 Parameter kind

Table 12 gives integer values as identifiers for quantities needed to describe a distribution.

Table 12 — Identifiers for statistical quantities

Kind	Description	Notes
0.	unspecified	the producer neglects to specify (usually unacceptable)
1.	unknown	unknown quantity
2.	mean	
3.	median	
4.	mode	
5.	minimum	extreme values not true location parameters
6.	maximum	
7.	(minimum + maximum) / 2	
8.	Tukey's trimean	
9.	generic location parameter	
10. – 31.	undefined	
32.	variance	
33.	standard deviation	
34.	median absolute deviation (MAD)	Actually 1.4826 (med(abs(x-med)) where the constant 1.4826 normalizes so that the expectation value of the mad is equal to the std. deviation of a normal distribution.
35.	(maximum – minimum)	extreme values not true location parameters
36.	generic scale parameter	
37.	skewness	

Kind	Description	Notes
38.	kurtosis	
39. – 65.	undefined	
66.	generic parameter I	for distributions parameterized by more than just location and scale
67.	generic parameter II	
68. – 95.	undefined	
96.	cumulative distribution function	as discrete pairs (x_i, F(x_i)) for i = 1…N as used in Type 2
97.	cumulative distribution function	as a B-spline representation used in Type 3
98. – 255	undefined	

NOTE 1 An application may well effect the same transformation regardless of which kind of values the record holds, e.g. linear transforms such as (x-mean)/stdev and (x-median)/mad.

NOTE 2 The range of parameters is wide. For a specific application it will be necessary to narrowly specify these. This is properly done in an application profile, or other requirements document.

7.3 Parameter origin

The (1 byte) value of Table 13 shall be used to indicate the origin of the parameter.

Table 13 — Origins of statistical data

Origin	Distribution of what quantity
0.	Unspecified – value(s) whose origin is not divulged
1.	Unknown – value(s) with undetermined origin
2.	Empirical – value(s) estimated from experiment and sample data
3.	Known a priori – value(s) known by design, or theoretical considerations. For a distribution this value would indicate it is known in closed-form.
4. – 254	Reserved

7.4 Distributions present

The (1 byte) value shall be used to indicate which of the impostor and genuine distributions are included in a record. The allowed values are given in Table 14. This field shall contain the value 0x01, 0x02 or 0x03. When both distributions are present the impostor distribution shall precede the genuine distribution.

Table 14 — Distribution information present

Value	Distributions present
0x01	Impostor
0x02	Genuine
0x03	Impostor and Genuine
0x04 - 0xFF	Reserved

7.5 Number of comparisons

The (4-byte) number of genuine or impostor comparisons used to estimate the Type 1, 2 or 3 information shall be encoded in this field. A value of zero shall be used when this value is unknown.

7.6 Pre-normalization flag

The (1 byte) value of Table 15 shall be used to indicate whether scores from the comparison subsystem exist on an arbitrary range or have been pre-normalized. For the purposes of this part of ISO/IEC 29159, this means that a fusion module may regard the scores produced by the comparison subsystem to be uniformly distributed on the range [0,1]. This supports direct use of scores without need for interpolation. See Annex C for information on the meaning of this field.

NOTE 1 This field is present in the Type 2, or 3 records for the genuine and impostor distributions. If a comparison subsystem produces pre-normalized impostor scores, the genuine scores will not be uniform, and vice versa. Thus it will never make sense for the records of this part of ISO/IEC 29159 to indicate that both the impostor and genuine scores are pre-normalized.

NOTE 2 Implementations conformant to BioAPI [1] return "FAR values". This means that internally generated impostor scores are either naturally on [0,1] or have been normalized by the expected impostor CDF of those scores. The result will be that the output impostor scores can be expected to be uniform on [0,1].

Table 15 — Pre-normalization codes

Pre-normalization status	Range of scores	Value (1 byte)
Not normalized	$-\infty < x < \infty$	0
Pre-normalized	$0 \le x \le 1$	1

8 Type 1 record

8.1 Purpose

The Type 1 record holds minimal statistical information about the impostor and/or genuine scores from a biometric system. This information may be used for rescaling scores before a fusion operation.

8.2 Format

8.2.1 Supporting datatype - Subtype A

Subtype A contains the kind (see clause 7.2), origin (clause 7.3) and value of a scalar statistic. The format is given in Table 16.

Table 16 — Subtype A format

Field	Status	Description	Length (bytes)	Data type	Allowed values	Example
1	M	Parameter kind	1	uint	See Table 12	3 (median)
2	M	Parameter origin	1	uint	0-3	2 (empirical)
3	M	Parameter value	8	double	Range of double	2.998×10^8

8.2.2 Definition

The format of a Type 1 record shall be that shown in Table 17. Either the impostor data or the genuine data or both shall be present (i.e. the valid sizes are 26 or 50 bytes).

Table 17 — Type 1 record format

Field	Status	Description	Length (bytes)	Data type	Allowed values	Example
1.	M	Type	1	uint	1	1
2.	M	Distributions present	1	packed bit field	0x01, 0x02, 0x03	0x01
3.	O	Impostor number of comparisons	4	uint	$[0,2^{32} - 1]$	40000
4.		Impostor distribution location	10	Subtype A		(3 1 2.998)
5.		Impostor distribution scale	10	Subtype A		(34 1 0.308)
6.	O	Genuine number of comparisons	4	uint	$[0,2^{32} - 1]$	240
7.		Genuine distribution location	10	Subtype A		(3 1 8.310)
8.		Genuine distribution scale	10	Subtype A		(34 1 1.406)

8.2.3 Type

The Type for a Type 1 record shall be 1 stored in 1 byte.

8.2.4 Distributions present

Those distributions present in the Type 1 record shall be recorded in the bits of a Distributions Present field.

8.2.5 Impostor number of comparisons

The number of comparisons used in the computation of the impostor score statistics shall be recorded as a Number of Comparisons field.

8.2.6 Impostor distribution location

If present, this Subtype A field shall contain the kind, origin and value for a location parameter of the impostor score distribution. If present, this value shall be followed by the scale information in 8.2.7.

NOTE If it is sensible that a normalization scheme involves only translation (i.e. no scaling), then the scale parameter of 8.2.7 can be set 1.

8.2.7 Impostor distribution scale

If present, this Subtype A field shall contain the kind, origin and value for a scale parameter of the impostor score distribution.

8.2.8 Genuine number of comparisons

The number of comparisons used in the computation of the genuine score statistics shall be recorded as a Number of Comparisons field.

8.2.9 Genuine distribution location

If present, this Subtype A field shall contain the kind, origin and value for a location parameter of the genuine score distribution. If present, this value shall be followed by the scale information in 8.2.10.

8.2.10 Genuine distribution scale

If present, this Subtype A field shall contain the kind, origin and value for a scale parameter of the genuine score distribution.

8.3 Use case (Informative)

Given two Type 1 records, one from a fingerprint comparison subsystem (A) and another from an iris comparison subsystem (B), score-level fusion could be implemented as the sum of z-normalized scores as:

$$s = (a - amean) / asigma + (b - bmean) / bsigma$$

where

a =	raw score from fingerprint comparison subsystem
b =	raw score from iris comparison subsystem
amean =	estimated mean of impostor scores from comparison subsystem A
asigma =	estimated standard deviation of impostor scores from comparison subsystem A
bmean =	estimated mean of impostor scores from comparison subsystem B
bsigma =	estimated standard deviation of impostor scores from comparison subsystem B

9 Type 2 record

9.1 Purpose

A Type 2 record shall contain cumulative distribution functions of either or both of the impostor and genuine comparison score distributions. If both distributions are present, the impostor distribution shall precede the genuine distribution.

NOTE 1 Example CDFs are shown in Annex A.

NOTE 2 Fusion modules requiring probability density functions (PDFs) may estimate them by numerically differentiating the CDFs. Type 2 does not include PDFs natively because of the need to specify an interval.

NOTE 3 If F(x) denotes a CDF, then its evaluation for score, a, involves the look-up of score, a, in the Subtype B two-array data structure. This may be implemented by means of a binary search of the first vector to find the index i for the interval $x_{i-1} \leq a < x_i$ such that interpolation between $F(x_{i-1})$ and $F(x_i)$ can be applied to get value F(a).

9.2 Format

9.2.1 Supporting datatype - Subtype B

Subtype B is a structure for discrete samples of a real-valued unidimensional function. It establishes a look-up table by including two arrays of equal length, N: the x values and the f(x) values. The values are sorted on x in increasing order. Thus:

1. If the i-th element of the first vector is x_i then i-th element of the second vector is $f(x_i)$;
2. $x_1 \leq x_i \leq x_N$ for all i = 1 … N.

The format shall be that given in Table 18.

Table 18 — Subtype B format

Field	Status	Description	Length (bytes)	Data type	Allowed values	Example
1.	M	Parameter kind	1	uint	96	96 (cdf)
2.	M	Parameter origin	1	uint	0-3	1
3.	M	Pre-normalized	1	uint	0, 1	0
4.	M	Number of comparisons	4	uint	$[0,2^{32} - 1]$	$1.5\ 10^9$
5.	M	Number of elements, N	4	uint	$0 \leq N \leq 2^{32} -1$	800
6.	M	N x-values	8N	double	range of double	(0.2, 0.4, 0.8)
7.	M	N f(x) values	8N	double	range of double	(7, -4, -1)

9.2.2 Definition

The format of a Type 2 record shall be that shown in Table 19. Either the impostor data or the genuine data or both shall be present (i.e. the valid sizes are 13+16N or 24+32N bytes).

Table 19 — Type 2 record format

Field	Status	Description	Length (bytes)	Data type	Allowed values	Example
1.	M	Type	1	uint	2	2
2.	M	Distributions present	1	packed bit field	0x01 - 0x03	0x01
3.	O	Impostor distribution	11+16N	Subtype B		One or both required
4.	O	Genuine distribution	11+16N	Subtype B		

NOTE 1 The value of N in the length fields is the number of (x, F(x)) pairs.

NOTE 2 The values contained in the Subtype B record for one of the distributions (say, the impostor) are usually empirically derived. If the underlying distribution is known, the values could be samples of the known CDF. For a Normal distribution the CDF is $0.5(1+\mathrm{erf}(x/\sqrt{2}))$.

9.2.3 Type

The type for a Type 2 record shall be 2. It shall be stored in 1 byte.

9.2.4 Distributions present

Those distributions present in the Type 2 record shall be recorded in the bits of a Distributions Present Subtype field.

9.2.5 Impostor distribution

If present, this Subtype B field shall contain the CDF of the impostor score distribution. The field shall contain monotonically increasing data.

9.2.6 Genuine distribution

If present, this Subtype B field shall contain the CDF of the genuine score distribution. The field shall contain monotonically increasing data.

9.3 Use case (Informative)

Given two Type 2 records, one from a fingerprint comparison subsystem (A) and the other from an iris comparison subsystem (B), score-level fusion could be implemented as:

$$s = -\log\left(M'_A(a) / N'_A(a)\right) - \log\left(M'_B(b) / N'_B(b)\right)$$

where

a = raw score from fingerprint comparison subsystem

b = raw score from iris comparison subsystem

M'_A = the PDF of genuine scores computed as the (numerical) derivative of the CDF of genuine scores from comparison subsystem A

N'_A = the PDF of impostor scores computed as the (numerical) derivative of the CDF of impostor scores from comparison subsystem A

M'_B = the PDF of genuine scores computed as the (numerical) derivative of the CDF of genuine scores from comparison subsystem B

N'_B = the PDF of impostor scores computed as the (numerical) derivative of the CDF of impostor scores from comparison subsystem B

NOTE 1 This formula is elaborated upon in [7] and ISO/IEC TR 24722:2007, Annex A [3].

NOTE 2 The impostor PDF for an iris system has been described in closed form [4]. The CDF would be an incomplete beta function (from sum of binomials) and thus would be recorded as having origin 3 in clause 7.3. It would be included in a Type 2 record by appropriate (i.e. sufficiently fine) sampling.

10 Type 3 record

10.1 Purpose

A Type 3 record shall contain the cumulative distribution functions of either or both of the impostor and genuine comparison score distributions. If both distributions are present the impostor distribution shall precede the genuine distribution. The record uses a B-spline representation of the paired (x, F(x)) elements of the Type 2 record and, ordinarily, it will be computed from such data. This record is a more compact alternative to large Type 2 records, and should be used when the number of (x, F(x)) pairs is impractically large for a Type 2 record. The B-spline shall be computed according to the algorithm documented in [5]. The degree of the B-spline shall be three (i.e. cubic).

10.2 Format

10.2.1 Supporting datatype - Subtype C

Subtype C is a structure for the coefficients and knots of a B-spline representation of a function. The spline is computed from n data points, and a specification of N << n knots (score values). The result is a set of coefficients for the knots. The spline is computed using least squares minimization with linear constraints. Storage is O(N) and thus N acts as an "accuracy" parameter. The format shall be that of Table 20.

Table 20 — Subtype C format

Field	Status	Description	Length (bytes)	Data type	Allowed values	Example
1.	M	Parameter kind	1	Uint	97	
2.	M	Parameter origin	1	Uint	0,1,2,3	
3.	M	Pre-normalized	1	Uint	0,1	0
4.	M	Number of comparisons, n	4	Uint	$[0,2^{32} - 1]$	$1.5\ 10^9$
5.	M	Degree of spline, K	1	Uint	$1 \le K \le 255$	3
6.	M	Number of knots, N	4	Uint	$1 \le N \le 2^{32} -1$	100
7.	M	Knot x values	8N	double	range of double	
8.	M	Coefficients	8C (see NOTE 2)	double	range of double	

NOTE 1 This structure is an appropriate container for the spline described in [5].

NOTE 2 The number of coefficients is C = N – K – 1. For a cubic spline the degree, K, is 3. The size of the knot and coefficient part of the record will be smaller than the n (x, F(x)) pairs of a Subtype B record when N + C < 2n. Thus for K = 3, space will be saved when N < n-2. The spline is effective because many fewer knots than data points can be used while maintaining interpolation accuracy. The product instantiating the record should determine the appropriate value for N.

NOTE 3 The "allowed values" are generic here. When a Subtype C instance is used, for example, in the Type 3 record of clause 10 the degree K shall be 3.

10.2.2 Definition

The record shall have the format given in Table 21. Either the impostor data or the genuine data or both shall be present (i.e. the valid sizes are 16N-18 or 32N-38 bytes).

Table 21 — Type 3 record format

Field	Status	Description	Length (bytes)	Data type	Allowed values	Example
1.	M	Type	1	uint	3	3
2.	M	Distributions Present	1	packed bit field	0x01 - 0x03	0x01
3.	O	Impostor distribution	12+8N+8(N-4)	Subtype C K=3		One or both required
4.	O	Genuine distribution	12+8N+8(N-4)	Subtype C K=3		

NOTE 1 The first derivative of the spline representation of the CDF is itself a spline. It represents the probability density function (PDF). It is continuous for all x. Equation (4) of [5] gives the formula for the derivative.

NOTE 2 This part of ISO/IEC 29159 requires the use of the linear constraints specified in [5] to ensure that the resulting spline is monotonic.

NOTE 3 The B-spline does not generally equal the original data at the knots; i.e. spline(xi) ≠ F(xi).

NOTE 4 The cubic function is of high enough degree to provide accurate interpolation.

NOTE 5 The B-spline is a more accurate representation of the function than a fit of the N knots because it is computed from n >> N points.

NOTE 6 Annex D presents C++ code for the evaluation of the spline function.

10.2.3 Type

The type for a Type 3 record shall be 3. It shall be stored in 1 byte.

10.2.4 Distributions present

Those distributions present in the Type 3 record shall be recorded in the bits of a Distributions Present record.

10.2.5 Impostor distribution

If present, this Subtype C field shall contain the CDF of the impostor score distribution. The field shall contain monotonically increasing data.

10.2.6 Genuine distribution

If present, this Subtype C field shall contain the CDF of the genuine score distribution. The field shall contain monotonically increasing data.

Annex A
(informative)

Document Overview

A.1 Overview

The standard defines the fusion information format (FIF) record as a container for the statistics of comparison scores generated by biometric comparison subsystems. An overview of the record and the definition of the common FIF header are given in clause 6. As summarized in Table A.1, the record can hold three types of data which are defined in clauses 8, 9, and 10. The types share some common elements that are presented in clause 7, before the types are formally defined in clauses 8, 9, and 10. An application may profile this part of the standard by calling out one of the three types, and restricting its optional content.

Table A.1 — Fusion information format type taxonomy

Type	Level	Description	Intended use	Example of score normalization
1	Score	Location and scale parameters of one or more of the genuine and impostor distributions.	To support any scaling function that uses only the location and scale parameters of the distributions	Rescaling achieved by use of one or more of the distributions, e.g. $y = (x-m_I) / s_I$ where m_I and s_I are, respectively, the mean and std. deviation of the impostor distributions.
2	Score	Empirical cumulative distribution functions (CDFs) of one or more of the genuine and impostor distributions	Any scaling operation that benefits from full distributional information	Rescaling using impostor distribution: $y = N_I(x)$ where $N_I(x)$ is the CDF of the impostor distribution and one minus an estimate of that comparison subsystem's false match rate (FMR).
3	Score	B-Spline function fit of Type 2 cumulative distribution function.	Any scaling operation that benefits from full distributional information	As for Type 2

A.2 Selection of the types

Users of this part of the ISO/IEC 29159 standard should note that Type 1, while very compact, will support only rudimentary score-level fusion methods. The alternative is to use Types 2, and 3 which fully encode the score distributions and are capable of supporting quite sophisticated fusion schemes. These should be used in preference to Type 1, because of likely accuracy benefits.

Between Types 2, and 3, it must be recognized that Type 3 is computed from essentially the data of a Type 2 record, and should be functionally equivalent. The computation of the Type 3 record will usually be parameterized to produce a result more compact than Type 2. Type 3, on the other hand, requires use of a numerical method to compute the spline representation. Although source code for Type 3 is not provided here it should be preferred over Type 2 because it is more compact.

A.3 Interoperability of the types

Interoperability in the FIF context refers to the use by a fusion module of, say, a Type 3 record from supplier A with a Type 2 record from supplier B. Users of this part of ISO/IEC 29159 should note that Type 1 offers limited interoperability with itself and with other Types. For example a Type 1 record embedding mean and standard deviation information will offer degraded performance when used with a Type 1 record embedding median and median absolute deviation information. Further Type 1 is not readily interoperable with Types 2 and 3. In the cases where a fusion module is provided with Type 1 and Type 2 records, interoperability may be achieved in two ways:

— Demotion would involve the computation of the Type 1 record's statistics from the Type 2 data. For example, the median is simply the 50^{th} percentile, and the mean may be estimated by sampling.

— Promotion would construct a Type 2 or 3 record from a Type 1, by making an assumption of a distributional form (e.g. normal), and then parameterizing it by the Type 1 location and scale parameters.

These options are not recommended, and should be considered only in cases where Type 2 or 3 data is unavailable. For these reasons it is strongly recommended that users should strongly profile this part of ISO/IEC 29159 before its use. This means that a formal document should be generated that includes the requirement that all suppliers should generate and provide, say, a Type 2 record containing both the impostor and genuine distributions. The document might be a formal profile, or a requirements document, a RFP, or some other binding guidance.

Users should also author such profiles to support migration from one product to another. Such a profile would require suppliers to provide, say, both the comparison algorithm library and a corresponding Type 3 genuine and impostor fusion information format record.

A.4 Extensibility

This part of ISO/IEC 29159 has been drafted to be extensible. Specifically, a revision of the standard could include other typed records. These might establish formats to support newer, alternative or more sophisticated fusion processes (perhaps, for example, based on joint densities), or different applications (e.g. contingent fusion [8]).

A.5 Quality directed fusion

The FIF standard does not explicitly include a record for comparison score statistics conditioned on biometric sample quality measurements [2]. Note, however, that a fusion module, initialized with FIF records, may nevertheless use input sample quality values as part of each subsequent fusion operation. In addition quality values might be used by a provider during the initial preparation of their FIF record.

Annex B
(informative)

Example Cumulative Distribution Functions

B.1 Overview

Figure B.1 shows two cumulative distribution functions from typical commercial biometric matchers. In each case, the scale of the x-axis is arbitrary reflecting the internal nature of the underlying comparison subsystem. The vertical axis is [0,1]. The stepped plots are the empirical cumulative distribution functions (ECDF), the smooth lines are cubic spline fits of the ECDFs. The ECDFs give, by definition, the fraction of comparison scores less than or equal to the abscissa. Therefore the spline passes through the convex steps viewed from "on top".

Figure B.1(a), was computed from 44 (x, F(x)) pairs covering x values on [-1,54]. The second plot, Figure B.1(b), was computed from 571 (x, F(x)) pairs covering x values on [-1,871]. The long right tails are not present because the plots were truncated at the (empirical) 95% quantiles for ease of use. The smooth curves are the Type 3 spline representations.

The use of spline-based FIF records supports evaluation of the CDF at arbitrary values, including:

— non-integer values,

— values outside the observed range, and

— integral values that were not observed in the original sample of scores.

But if the comparison subsystem natively produces only integral scores, then why is the spline relevant? The alternative, a Type 2 look-up table could be used instead but it has the disadvantage of size (it's bigger) and might not include all possible integer values. This latter situation would require the fusion module to perform interpolation (or extrapolation). The spline function evaluates to 0 or 1 for values outside the original interval. If the CDF had been computed with a larger set of scores then more extreme values would have been observed (larger maxima and smaller minima) and this would give a different estimate of the CDF.

In summary, the spline is recommended because:

— it interpolates, and

— its first two differentials are continuous (supporting fusion methods that depend on this).

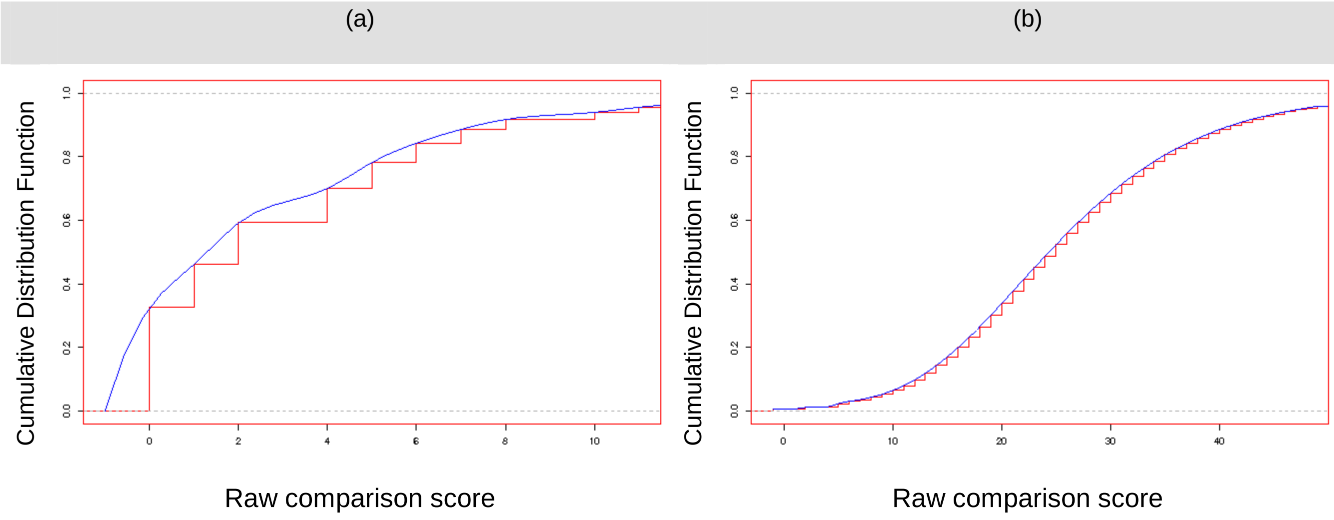


Figure B.1 — Example CDFs and their spline representations

Annex C
(informative)

Use of pre-normalized data

C.1 Background

Suppose a biometric comparison subsystem internally transforms its raw scores so that its output impostor scores are uniformly distributed on [0,1]. The subsystem will do this by internally applying some estimate of the impostor CDF to its internal scores. This is the default practice in BioAPI [1] where scores are actually quoted as false match rates i.e. $s_{output} = 1 - N_{calibration}(s_{internal})$ where the $N_{calibration}$ is an estimate of the impostor CDF serving as a calibration function.

The impostor distribution is used in this manner because it is considered to be insensitive to variations in sample properties such as environment and population. This stability of the impostor distribution is useful because it allows a portable cross-application normalization of scores.

C.2 Example

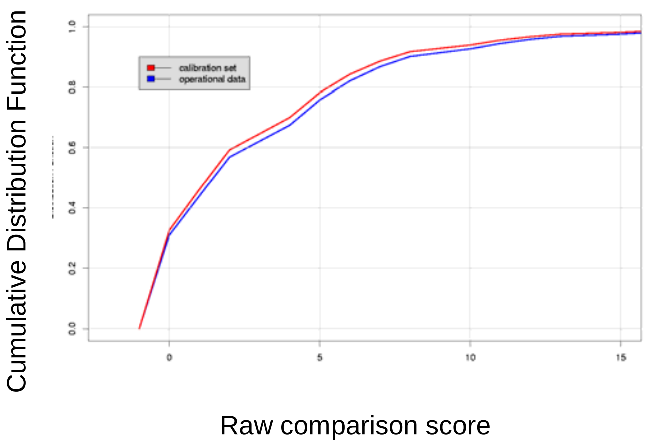
Practically there will be some change in the impostor distribution across applications. Figure C.1(a) shows

— the CDF of the impostor scores obtained by comparing samples from a calibration set of images, and

— the CDF of the impostor scores obtained by comparing samples from a disjoint set of images gathered under different conditions.

The differences are small but significant. The effect of pre-normalization is simulated in Figure C.1(b): It shows, that after 1-N(x) normalization, the distribution of the calibration set scores is perfectly uniform (by definition) but the operational data's CDF is higher.

(a)	(b)
Top trace – calibration set; bottom – operational data	Top trace – operational data; bottom – calibration set



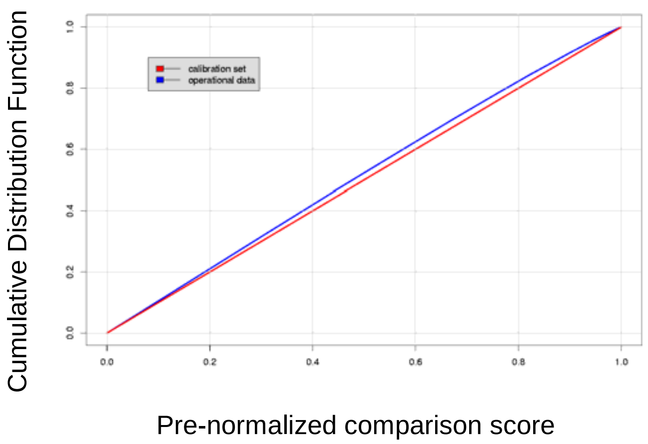


Figure C.1 — Example CDFs of internal comparison scores and pre-normalized scores

NOTE The genuine scores are not addressed in this section - they will have different distributions, and will not be uniform with or without pre-normalization.

C.3 Best Practice

Thus the use of pre-normalized data comes with a caveat that the actual uniformity of pre-normalized impostor scores is dependent on the stability of the scores. The FIF format addresses this by defining alternative formats for

— arbitrarily distributed scores, and

— pre-normalized scores, for which the impostor scores are calibrated to be uniform on [0,1].

If a supplier provides a FIF record giving pre-normalized scores then this is an implicit statement that operationally the uniformly distributed impostor scores will be realized over extended operational periods. If a supplier provides Type 2 or 3 records, with an impostor CDF, then reported impostor scores, transformed by this CDF, should also be uniform. The difference is who executes the transformation: the provider does it internally or natively, or the application (i.e. integrator). In any case, the uniformity of the result would be subject to test.

The best-practice situation is for an application to collect operational impostor scores and to generate a FIF record specific to the deployed situation. This might be updated periodically to account for trends (e.g. seasonal or secular) in the data.

Annex D
(informative)

Source for evaluation of spline

The following code fragment may be used to evaluate the spline representation [5] CDF held in a Type 3 record.

```
// Evaluate k-th degree B spline function for the value t. The value t lies between
// knots j and j+1.  The function is recursive.
double B(const unsigned int j, const unsigned int k, const double t)
{
   (k == 0)
      return (knots[j] <= t && t < knots[j+1]) ? 1.0 : 0.0;

   const double c1 = (knots[j+k]   == knots[j]  ) ? 0 : (t - knots[j])     / (knots[j+k]   - knots[j]  );
   const double c2 = (knots[j+k+1] == knots[j+1]) ? 0 : (knots[j+k+1] - t) / (knots[j+k+1] - knots[j+1]);

   return c1*B(j, k-1, t) + c2*B(j+1, k-1, t);
}

// linear search over the strictly increasing knots for the interval containing value t
unsigned int i = 0;
for ( ; knots[i+1] <= t ; i++ );

// given the interval compute the value of the spline at this t-value
double value = 0.0;
for ( unsigned int j = i – k ; j <= i ; j++ )
   value += x[j+1] * B(j, k, t);
```

Bibliography

[1] ISO/IEC 19784-1, *Information technology — Biometric application programming interface — Part 1: BioAPI Specification*

[2] *Discriminative multimodal biometric authentication based on quality measures.* J. Fierrez-Aguilar, J. Ortega-Garcia, J. Gonzalez-Rodriguez, and Josef Bigun. Pattern Recognition, 38(5):777–779, May 2005. http://www.itl.nist.gov/iad/894.03/quality/biblio.html

[3] ISO/IEC TR 24722:2007, *Information technology — Biometrics — Multimodal and other multibiometric fusion*

[4] *The importance of Being Random*, J. Daugman, Pattern Recognition, Vol. 36, No. 2, pp. 279–291, February 2003

[5] *Constrained Monotone Regression of ROC Curves and Histograms Using Splines and Polynomials*, T. Kanungo, D. M. Gay, and R. M. Haralick. In Proceedings of the International Conference on Image Processing, Washington D.C., October 23-26, 1995. Volume 2, IEEE Computer Society, 1995

[6] *Monotone Piecewise Cubic Interpolation*, Fred Fritsch and R Carlson, SIAM Journal on Numerical Analysis, Volume 17, Number 2, April 1980, pages 238-246

[7] *Handbook of Multibiometrics*, A. Ross, K. Nandakumar, and A. K. Jain, Springer International Series on Biometrics, Vol. 6, 2006, XXII, 202 p., 65 illus., Hardcover. ISBN: 0-387-22296-0

[8] *When to Fuse Two Biometrics*, E. Tabassi, G.W. Quinn, and P. Grother, IEEE CS Conference on Computer Vision and Pattern Recognition (CVPR '06), June 2006

[9] ISO/IEC JTC1/SC 37 Standing Document 2 — Harmonized Biometric Vocabulary. This document has been developed within Working Group 1 of SC 37

ICS 35.040
Price based on 23 pages