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Information technology — Biometric data interchange formats —

Part 8: Finger pattern skeletal data

Technologies de l'information — Formats d'échange de données biométriques —

Partie 8: Données des structures du squelette de l'empreinte

Reference number
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Foreword

ISO (the International Organization for Standardization) and IEC (the International Electrotechnical Commission) form the specialized system for worldwide standardization. National bodies that are members of ISO or IEC participate in the development of International Standards through technical committees established by the respective organization to deal with particular fields of technical activity. ISO and IEC technical committees collaborate in fields of mutual interest. Other international organizations, governmental and non-governmental, in liaison with ISO and IEC, also take part in the work. In the field of information technology, ISO and IEC have established a joint technical committee, ISO/IEC JTC 1.

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

The main task of the joint technical committee is to prepare International Standards. Draft International Standards adopted by the joint technical committee are circulated to national bodies for voting. Publication as an International Standard requires approval by at least 75 % of the national 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 and IEC shall not be held responsible for identifying any or all such patent rights.

ISO/IEC 19794-8 was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee SC 37, *Biometrics*.

This second edition cancels and replaces the first edition (ISO/IEC 19794-8:2006), Clauses 6, 7 and 8 and Annex B of which have been technically revised. It also incorporates the Technical Corrigendum ISO/IEC 19794-8:2006/Cor.1:2011.

ISO/IEC 19794 consists of the following parts, under the general title *Information technology — Biometric data interchange formats*:

- *Part 1: Framework*
- *Part 2: Finger minutiae data*
- *Part 3: Finger pattern spectral data*
- *Part 4: Finger image data*
- *Part 5: Face image data*
- *Part 6: Iris image data*
- *Part 7: Signature/sign time series data*
- *Part 8: Finger pattern skeletal data*
- *Part 9: Vascular image data*
- *Part 10: Hand geometry silhouette data*
- *Part 11: Signature/sign processed dynamic data*

The following parts are under preparation:

- *Part 13: Voice data*
- *Part 14: DNA data*

Introduction

With the interest of implementing interoperable personal biometric recognition systems, this part of ISO/IEC 19794 establishes a data interchange format for pattern-based skeletal fingerprint recognition algorithms. Pattern-based algorithms process sections of biometric images. Pattern-based algorithms have been shown to work well with the demanding, but commercially driven, fingerprint sensor formats such as small-area and swipe sensors.

The exchange format defined in this part of ISO/IEC 19794 describes all characteristics of a fingerprint in a small data record. Thus it allows for the extraction of both spectral information (orientation, frequency, phase, etc.) and features (minutiae, core, ridge count, etc.). Transformations like translation and rotation can also be accommodated by the format defined in this part of ISO/IEC 19794.

With this part of ISO/IEC 19794 for pattern-based skeletal representation of fingerprints:

— interoperability among fingerprint recognition vendors based on a small data record is allowed;

— proliferation of low-cost commercial fingerprint sensors with limited coverage, dynamic range, or resolution is supported;

— a data record that can be used to store biometric information on a variety of storage mediums (including, but not limited to, portable devices and smart cards) is defined;

— adoption of biometrics in applications requiring interoperability is encouraged.

Note that it is recommended that biometric data protection techniques in ANSI X9.84 or ISO/IEC 15408 be used to safeguard the biometric data defined in this part of ISO/IEC 19794 for confidentiality, integrity and availability.

Information technology — Biometric data interchange formats —

Part 8:
Finger pattern skeletal data

1 Scope

This part of ISO/IEC 19794 specifies the interchange format for the exchange of pattern-based skeletal fingerprint recognition data. The data format is generic in that it can be applied and used in a wide range of application areas where automated fingerprint recognition is involved.

This part of ISO/IEC 19794 also specifies elements of conformance testing methodology, test assertions, and test procedures as applicable to the interchange format for the exchange of pattern-based skeletal fingerprint recognition data.

This part of ISO/IEC 19794 establishes

— test assertions of the structure of the finger pattern skeletal data format as specified in this part of ISO/IEC 19794 (Type A Level 1 as will be defined in ISO/IEC 19794-1:2011/Amd.2),

— test asssertions of internal consistency by checking the types of values that may be contained within each field (Type A Level 2 as will be defined in ISO/IEC 19794-1:2011/Amd.2).

This part of ISO/IEC 19794 does not establish

— test of conformance of CBEFF structures required by this part of ISO/IEC 19794,

— test of consistency with input biometric data record (Level 3),

— test of other characteristics of biometric products or other types of testing of biometric products (e.g. acceptance, performance, robustness, security),

— test of conformance of systems that do not produce ISO/IEC 19794-8 records.

2 Conformance

A biometric data record conforms to this part of ISO/IEC 19794 if it satisfies all of the normative requirements related to:

a) its data structure, data values, and the relationships between its data elements, as specified throughout Clause 7 for the finger pattern skeletal data record format and Clause 8 for the finger pattern skeletal data card format of this part of ISO/IEC 19794;

b) the relationship between its data values and the input biometric data from which the biometric data record was generated, as specified throughout Clause 7 for the finger pattern skeletal data record format and Clause 8 for the finger pattern skeletal data card format of this part of ISO/IEC 19794.

A system that produces biometric data records is conformant to this part of ISO/IEC 19794 if all biometric data records that it outputs conform to this part of ISO/IEC 19794 (as defined above) as claimed in the Implementation Conformance Statement (ICS) associated with that system. A system does not need to be capable of producing biometric data records that cover all possible aspects of this part of ISO/IEC 19794, but only those that are claimed to be supported by the system in the ICS.

A system that uses biometric data records is conformant to this part of ISO/IEC 19794 if it can read, and use for the purpose intended by that system, all biometric data records that conform to this part of ISO/IEC 19794 (as defined above) as claimed in the ICS associated with that system. A system does not need to be capable of using biometric data records that cover all possible aspects of this part of ISO/IEC 19794, but only those that are claimed to be supported by the system in an ICS.

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.

ISO/IEC 19794-1:2011, *Information technology — Biometric data interchange formats — Part 1: Framework*

ISO/IEC 7816-6:2004, *Identification cards — Integrated circuit cards — Part 6: Interindustry data elements for interchange*

ISO/IEC 7816-11:2004, *Identification cards — Integrated circuit cards — Part 11: Personal verification through biometric methods*

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
sweat pore
minute opening in the dermis, allowing loss of fluid as a part of the temperature control of the body

5 Abbreviated terms

For the purposes of this document, the following abbreviated terms apply.

BER	Basic Encoding Rules
BIT	Biometric Information Template
CBEFF	Common Biometric Exchange Formats Framework
DO	Data Object
ppcm	pixels per centimetre

6 Determination of finger pattern skeletal data

This part of ISO/IEC 19794 for finger pattern interchange data is based on the skeleton representation of friction ridges. Since the result of different skeleton generation algorithms will differ at a maximum of about a quarter of the ridge width this will have no impact on interoperability. In order to get a robust skeleton of the ridges a noise reduction and regularization may take place on the raw image. The direction encoding of the skeleton line elements is included in the interchange data record. The start and endpoints of the skeleton ridgelines are included as real or virtual minutiae, and the line from start to endpoint is encoded by successive direction changes. In the following, first the minutiae characteristics and then the encoding definition for one skeleton line is described.

6.1 Minutia

Minutiae are points located at the places in the fingerprint image where friction ridges end or split into two ridges.

6.1.1 Minutia type

Each minutia point has a "type" associated with it. There are two major types of minutia: a "ridge ending" represented by the 2-bit value 01 and a "ridge bifurcation" or split point represented by 2-bit value 10. Points with three or more intersecting ridges (trifurcations, etc.) will be treated as a "ridge bifurcation" type.

Ridge skeletons require the use of both real and "virtual" minutiae. Virtual minutiae are points on the fingerprint image where a real ridge ending or a bifurcation does not exist, but a point is required to finish, or continue, a skeleton ridgeline. Virtual minutiae have thus two types: virtual endings and virtual continuations.

— Virtual endings are necessary to describe skeleton lines ending at the image boundary or at border lines to those areas where there is insufficient image quality to determine ridges and real minutiae points (see Figure C.3). They are also needed to finish the encoding of a closed loop (Table C.1). Virtual endings have been assigned the 2-bit value 00.

— In rare cases a skeleton line description will require the insertion of a virtual minutia point on a ridgeline. For example, such points will be required to begin an encoding of a closed loop for which no real minutiae exist, as well as to describe ridges with high curvature at a sufficient accuracy (see note about maximal curvature in 6.2.4). These are called "virtual continuation" and have been assigned the 2-bitvalue 11 (Table C.1).

6.1.2 Minutia location and coordinate system

The coordinate system used to express the position of the minutiae points of a fingerprint shall be a Cartesian coordinate system. Points shall be represented by their x and y coordinates, where x increases to the right and y increases downward (opposite of the pointing direction of the finger), when viewing on a latent print of the finger (see Figure 1). Note that this is in agreement with most imaging and image processing use. When viewing on the finger, x increases from right to left as shown in Figure 1. All x and y values are non-negative. For the skeletal pattern record format, the resolution is specified in the representation header, see.7.4. For the skeletal pattern card format, the resolution of the x and y coordinates of the minutia shall be in metric units. The granularity is one bit per five hundredth of a millimetre in the normal format and one tenth of a millimetre in the compact format:

1 unit = 0,05 mm (normal format) or 0,1 mm (compact format).

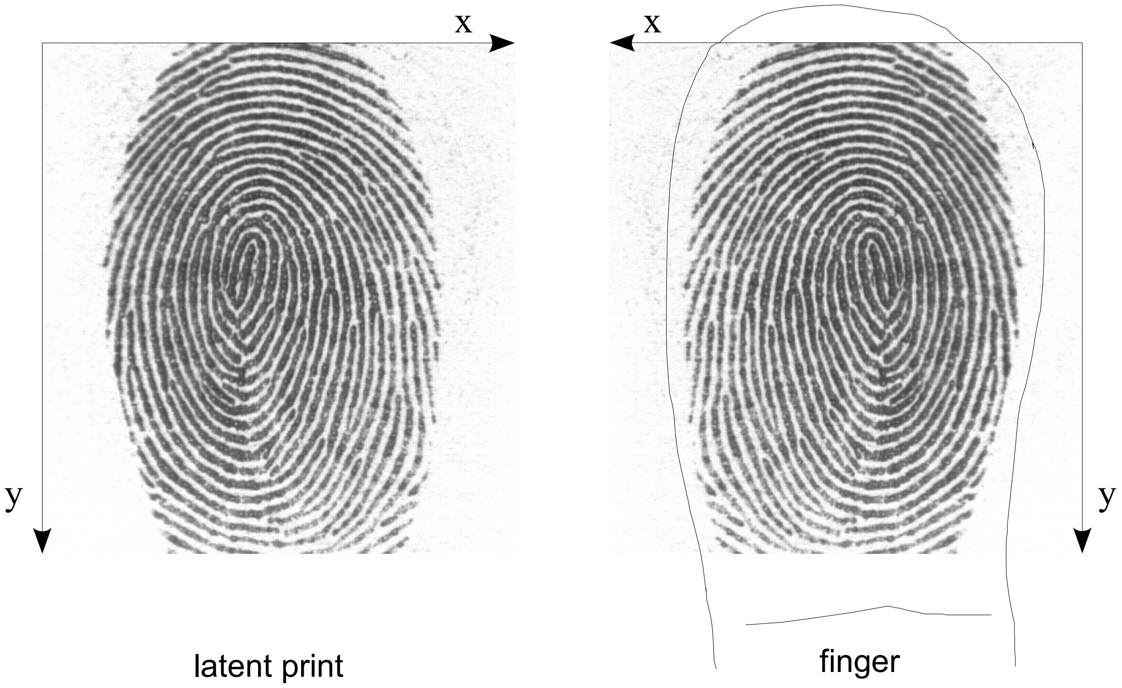

Figure 1 — Coordinate system

The position of the minutia for a ridge ending shall be defined as the coordinates of the skeleton point with only one neighbour pixel belonging to the skeleton.

NOTE In some format types of ISO/IEC 19794-2 a ridge ending refers to the point of bifurcation of the valley in front of the ridge.

The position of the minutia for a ridge bifurcation shall be defined as the point of forking of the skeleton of the ridge. In other words, the point where three or more ridges intersect is the location of the minutia.

The position of a virtual ending shall be defined like the position of a real ridge ending.

The position for the minutiae type “virtual continuation” is not evaluated by comparison algorithms, that analyse minutiae points and angles only. Minutiae of this type are only used for reconstructing the skeleton but may support subsequent classifications of the reconstructed pattern. One may assign any point on the skeleton necessary to increase the accuracy of the ridge line description (Table C.1).

6.1.3 Angle conventions

The minutiae angle is measured increasing counter clockwise starting from the horizontal axis to the right. The angle of a minutia is scaled to fit the bit width of the data field defined in the representation header.

The direction of a ridge skeleton endpoint is defined as the angle between the tangent to the ending ridge and the horizontal axis extending to the right of the ridge ending point.

A ridge skeleton bifurcation point has three intersection ridges. The two ridges enclosing the ending valley encompass an acute angle. The direction of a ridge bifurcation is defined as the mean direction of their tangents. Where each direction is measured as the angle the tangent forms with the horizontal axis to the right.

The direction of the lines starting or ending at a points with more than three arms (trifurcation, etc.) shall be defined like the direction of a real ridge ending.

The direction of a virtual ending shall be defined like the direction of a real ridge ending.

The direction for the minutia type “virtual continuation” is not evaluated by comparison algorithms, that analyse minutiae points and angles only. Minutiae of this type are only used for reconstructing the skeleton but may support subsequent classifications of the reconstructed pattern. One may assign the mean of the incoming and outgoing direction or the outgoing direction (Table C.1).

6.1.4 Differences to minutia data in ISO/IEC 19794-2 – Finger minutia data

The definition of the minutia position and direction is identical with ISO/IEC 19794-2:2005 card format (Format type ‘0006’) with

- minutia placement on a ridge bifurcation encoded as a ridge skeleton bifurcation point and
- minutia placement on a ridge endpoint encoded as a ridge skeleton endpoint.

To compare minutiae with any other definition, a position and direction correction may be necessary. There may be performance interoperability differences with the other format types of ISO/IEC 19794-2.

The angular resolution of minutiae in the finger pattern skeletal data record is defined in the header. The minimal resolution allowed is 16 directions, that is 22,5° per least significant bit. A resolution below the recommended 64 directions (5,625°)(Table 1: Bit-depth of direction code start and stop direction) may cause a decrease in match quality for purely minutiae based comparison algorithms. This recommendation corresponds to the angular resolution of the compact card format in finger minutiae data.

There are no virtual minutiae (type ID 00 and 11) in the finger minutiae data format.

There is no minutia type “other” (type ID 00) in the skeletal pattern data format.

Point with more than three arms (trifurcation, etc.) are not mentioned in the finger minutiae data, so they may be omitted or encoded as “other”. In the finger pattern skeletal data these structures get the type “bifurcation”.

6.2 Encoding the skeleton ridge line by a direction code

6.2.1 Direction code

Each line in the skeleton image is encoded as a polygon. Therefore, each polygon element is taken from a fixed set of line elements (defined in Clause 6.2.4). The line starts at an offset coordinate with a starting direction and the following minutia characteristics:

- minutia type (2 bits: 00 virtual ending, 01 ridge ending, 10 ridge bifurcation, 11 virtual continuation);
- minutia direction (bit-depth defined in the representation header, range: 0-360 degrees scaled according to bit-depth);
- x-coordinate (bit-depth defined in the representation header);
- y-coordinate (bit-depth defined in the representation header);
- number of direction elements following (8 bits).

The successive polygonal elements are defined by their direction change relative to the previous element or for the first element relative to the minutia direction, scaled and rounded to the direction code range and resolution (6.2.4). The length of each element is a function of the direction change (6.2.4):

- direction change (bit-depth and resolution defined in the representation header, data type is a signed integer - the smallest negative number 10…0 is not used for direction change); (e.g. for bit-depth of 4 and 32 directions on 180° the signed integer range from –7 to 7 is scaled to the angle range from –39,375° to +39,375°;

- or in situations of high ridge line curvature one may wish to store direction elements at higher spatial resolution. Therefore one can switch between two different resolution levels. With the smallest negative number 10…0 the resolution level is switched between normal or high. A line encoding will always start at normal resolution. On the first occurrence of 10…0 in a line code switch to high resolution level in using half the step length, on the second occurrence switch back normal resolution and full step length etc. (Table C.2).

— the direction change is repeated until the line end is reached;

— minutia type of line end (2 bits: 00 virtual ending, 01 ridge end, 10 ridge bifurcation, 11 virtual continuation).

If the skeleton line ends at a virtual ending (type number 00), the relative position of the minutia on the line element follows:

— the relative minutia position l/S_n is scaled to the range 0-3 via min(3, floor($4l/S_n$)) and stored as unsigned integer of length 2 bits, where l is the distance between the start of the last line element and the minutia, and S_n the step length of the last line element (Figure 2).

— If the skeleton line ends at a true minutia (type number 01 or 10) or is interrupted by a virtual continuation (type number 11) a byte-aligned minutia description follows. In order to keep the alignment overhead small it is done in the following manner: If the previously stored minutia type of the line end is already starting byte aligned, the minutia data is completed by appending its direction and position. On unaligned ending type, it is repeated at the start of the next byte followed by direction and position.

Thus the encoding continues with the following:

— If the previously stored minutia type of the line end is not starting byte aligned, it is repeated at the start of the next byte. Any unused bits caused by this alignment are filled with zeros.

— minutia direction (bit-depth defined in the representation header, range 0-360 degrees scaled according to bit-depth);

— x-coordinate (bit-depth defined in the representation header).

— y-coordinate (bit-depth defined in the representation header).

If the ending minutia is of type virtual continuation (type number 11) the line description continues with:

— the number of direction elements following (8 bits) and direction elements as described above.

Any unused bits of the last byte for each encoded line is filled with zeroes to get a byte aligned beginning for the next line encoding.

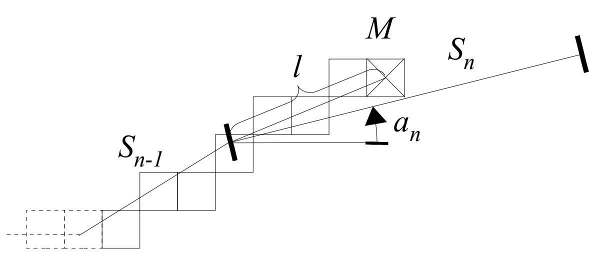

Figure 2 — The relative minutia position on a polygon line element is the ratio l/S_n, where S_n is the length of the line element passing the minutia M and l is the distance between the start of S_n and minutia M. α_n is the angle of S_n.

6.2.2 General skeleton line encoding rules

To keep the encoding size small a line shall start with a real minutia (type 01 or 10) if possible.

There are no restrictions about the use of virtual continuation minutiae or high resolution mode.

NOTE 1 Virtual continuation minutia and the high resolution mode are “tools” to describe the ridges. One may prefer one method to describe high curvature and use the other to mark a line passing a bifurcation, a core or delta or extreme values in curvature. But these additional interpretations will increase the encoding size and can only be used in a non interoperable manner.

No assumption shall be made about the order of the line encodings in the record.

The skeleton shall be encoded only for image areas where the ridge lines are displayed with a sufficient quality (Figure C.3).

NOTE 2 A one bit quality map is implicitly defined: At image areas with no encoded ridge line nearby the quality is 0 or not sufficient and at a image area with an encoded ridge line nearby the quality is 1 or sufficient. With the zonal quality data in the extended data area a multi-bit quality map may be defined in addition.

To judge the descriptive quality of the skeleton line encodings, one has to compare its reconstructed ridge lines with the fingerprint image the encoding comes from. The reconstructed ridge lines shall describe the fingerprint image in ridge position and structure, thus the following rules apply:

— The reconstructed skeleton line polygon element shall be inside the area of the ridge it is describing for most part of its length, i.e. at least 50%. A threshold in the range of 5% may be appropriate (best practice). This value depends on the reconstruction and comparison quality requirements of the application.

— The reconstructed skeleton line shall never be inside the area of any other ridge but the one it is describing.

— The reconstructed skeleton line shall preserve the topology of the ridges (see the definition of skeleton).

6.2.3 Constructing direction elements

For constructing the direction change α_i between two successive polygonal elements see Figure 3 and Figure 4. First, draw a circle, of radius equal to the polygon element length, around the current point. Obtain the intersection point between the circle and the skeleton line the in forward direction. The direction towards this point is scaled according to the bit-depth of the direction code. The difference between this direction and the previous line element is stored. The end point of this new polygon element with the fixed length and its digitised direction serves as the next starting point.

The previous construction is done with direction independent step size. For the general direction dependent step size replace the circle in the description above by the step size dependency defined in Clause 6.2.4.

In order to minimize integration of digitalisation error, each starting point must be computed with relatively high accuracy, i.e. its resolution shall be at least 100 times finger than the spatial resolution of the minutiae.

If the skeleton line ends during a step it is linearly extended to fill the polygon element length. The line encoding is completed with the minutiae type. For a true minutiae ending, its direction and the endpoint coordinates are stored. For a virtual ending, the relative minutia position on the current step is stored.

If the direction change of the skeleton line cannot be described by a direction element, the line encoding shall be interrupted by a “virtual continuation” and a new line encoding shall begin with the same point without repeating the minutia data.

A bifurcation (trifurcation, etc.) (Figure 4 and Figure C.2) is represented by two (or more) skeleton line encodings. One skeleton line passes the bifurcation without a real minutia at its position (Figure 4). All other lines end or start here and are assigned the type “bifurcation”. It is recommended to use the straightest ridge line passing the bifurcation without encoding a real minutia.

NOTE The most straight line is probably the dominant line, for which repetitive encodings with this part of ISO/IEC 19794 will not result in different line encodings - while the branching off line may swap from bifurcation to a ridge ending. i.e. depending from the sensor conditions in some images a bifurcation seems to be a ending with the dominant line passing through.

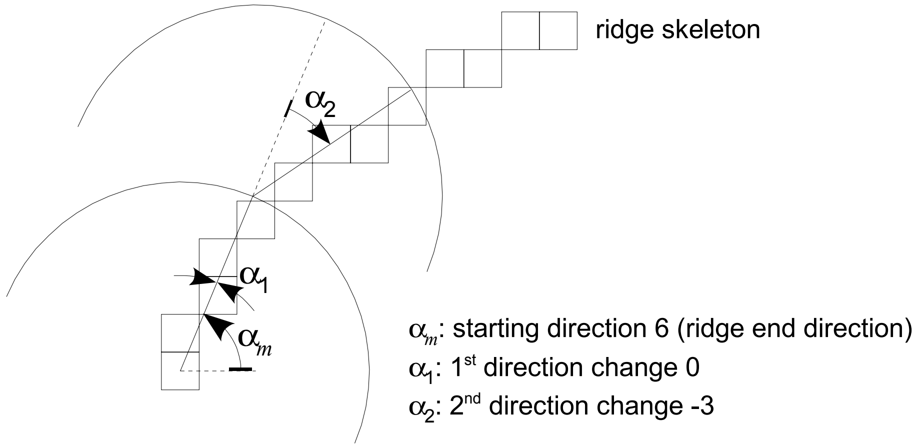

Figure 3 — The direction encoding starting from a skeleton end point. A bit-depth of 4 is used for direction change

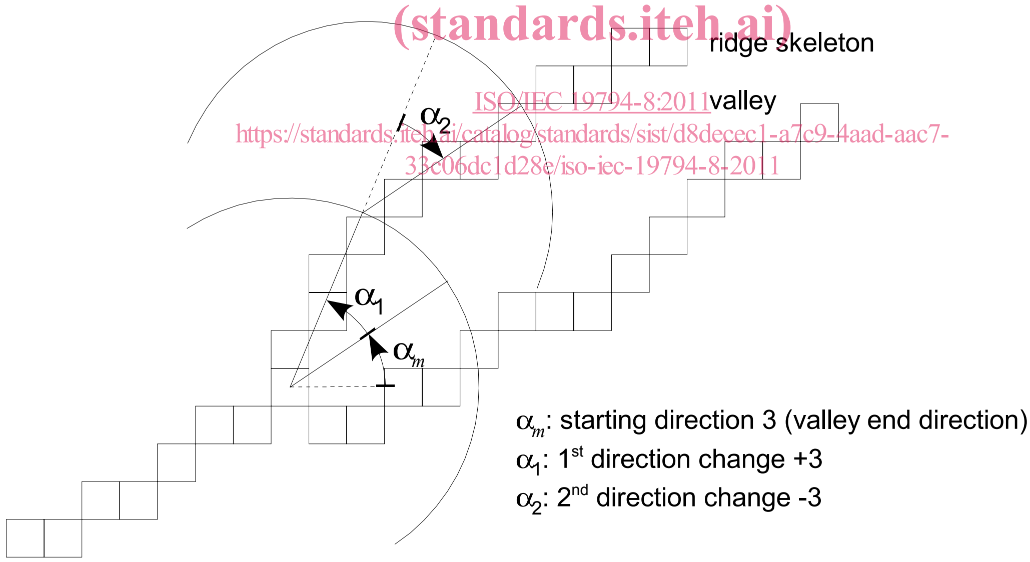

Figure 4 — The direction encoding starting from a skeleton bifurcation point. A bit-depth of 4 is used for direction change

6.2.4 Direction element length

At most steps the direction change will be straight or nearly straight. With an increase step length on small direction changes and reduced angular range the number of direction elements are reduced.

The direction change dependant step size (Figure 5) and resolution is characterised by 4 parameters:

— The number of directions, N_π, on π or 180°. This gives the angular resolution, e. g. with N_π = 32 the resolution is 5,625°.

— With the bit-depth for one direction code element one gets the number of possible directions at each step. Since the change is symmetric to 0, the angular range is

$$\alpha_{max} = \pm(180° / N_\pi)\,(2^{\text{bit-depth} -1} - 1) \qquad (1)$$

NOTE 1 With a resolution of 5,625° and at a bit-depth of 4, this gives a maximal bending of $\alpha_{max} = \pm 39{,}375°$

— The step length for going straight, S_s.

— The maximal displacement perpendicular to the current direction, S_p. In the representation header this value is stored relative to the straight step size, S_s, as $256 \times S_p/S_s$. If $256 \times S_p/S_s$ is set to 0 in the representation header a constant step length of S_s for all direction elements is used.

The design characteristics for the direction dependant step size are

— constant angular resolution, i. e. the distance between subsequent bending angles, α_n, is constant: $|\alpha_i - \alpha_{i\pm1}|$ = constant for all $i \in \{.., -2, -1, 0, 1, 2, ..\}$.

— constant spatial accuracy for all direction changes, i. e. the distance between subsequent steps, $\vec{r}_i$, is constant: $|\vec{r}_i - \vec{r}_{i\pm1}|$ = constant for all $i \in \{.., -2, -1, 0, 1, 2, ..\}$.

With these conditions the endings of all of possible directions, $\vec{r}_i$, for one step are located on two circlular arches as shown in Figure 5. Thus the direction dependant step size, $|\vec{r}_i|$, is defined by:

$$|\vec{r}_i| = \begin{cases} \dfrac{(S_s^{\,2} + 4S_p^{\,2})}{4S_p}\sin(2\varphi - |\alpha_i|) & \text{for } S_p > 0 \\ S_s & \text{for } S_p = 0 \end{cases} \qquad (2)$$

with the angle α_i between current direction and step $\vec{r}_i$ defined as:

$$\alpha_i = 180°\, i / N_\pi \qquad (3)$$

and where:

— $\varphi = \arctan(2S_p / S_s)$,

— $i \in \{.., -2, -1, 0, 1, 2, ..\}$ is the number of the direction change,

— S_s is the step length for going straight,

— S_p is the maximal displacement perpendicular to the current direction, and

— N_π is the number of directions on π or 180°.

An example for the angle dependant step size is given in Annex C.

NOTE 2 The maximal curvature of the polygon is achieved with the minimal step size $r_{min} = r(\alpha_{max})$ from (2) at the maximal bending angle α_{max} from (1). A polygon with constant bending angle α_{max} and constant element length r_{min} has a radius $R = 180°\, r_{min} / (\pi\, \alpha_{max})$. With $S_s = 16$, $S_p = 3{,}75$, and $\alpha_{max} = 39{,}375°$, a minimal step length $r_{min} = 3{,}9$ and a radius of 5,7 pixel at a resolution of 100 ppcm is attained. At high resolution level the step length is cut in half, $r_{min} = 1{,}95$, thereby getting a radius of 2,85 pixels. With these settings a u-turn down to 0,6mm Sdiameter may be represented by a polygon without interruption by a virtual continuation minutia.

