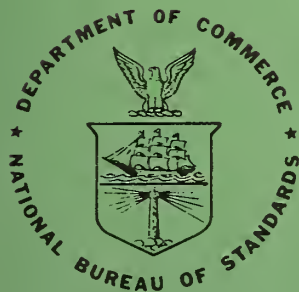


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TECHNICAL NOTE

443

**A Computer Oriented
Single-Fingerprint
Identification System**



**U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards**

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A Computer Oriented Single-Fingerprint Identification System

J. H. Wegstein

Center for Computer Sciences and Technology
Institute for Applied Technology
National Bureau of Standards
Washington, D.C. 20234

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A Computer Oriented Single-Fingerprint Identification System

by J.H. Wegstein

A procedure is described for computing a set of numerical descriptors that identify a single fingerprint. The procedure starts with the X and Y coordinates and the individual directions of the minutiae (ridge endings and bifurcations) of a fingerprint impression. Sets of descriptors are computed corresponding to groups or constellations of these minutiae. Descriptors corresponding to various fingerprint impressions are stored on magnetic tape. A fragment of a fingerprint impression such as occurs in a latent fingerprint may also be used.

A second computer program reads the descriptors corresponding to two different fingerprint impressions from magnetic tape. A score is computed that indicates how well the two impressions match. Preliminary experimental results suggest that this procedure might be suitable as a basis for a single-fingerprint classification system.

Key words: Classification, computer, descriptor, file, fingerprint, identification, pattern-recognition.

1. Introduction

In all of the fingerprints ever studied, no two impressions from different fingers have ever been found to be identical in minute detail. Furthermore, the minute details or minutiae of a fingerprint never change throughout the normal life of a finger. Accordingly, the single fingerprint invites increased attention as a means for human identification where tools such as the electronic digital computer are available to handle the information that can be related to the fingerprint impression.

Numerous schemes exist whereby a classification or set of descriptive symbols is developed which describe the fingerprints of a particular individual. The classification is usually kept on the same standard eight inch square card with the ten fingerprints of an individual, and a collection of these cards can be ordered and filed according to the classification. Then, starting with the fingerprints of an unknown person, a classification can be made and the file can be searched for a matching classification. Several identical classifications may be found in the file and a comparison of the fingerprints is then required to uniquely identify the individual.

The Henry Classification System¹. with modern extensions is widely used for large fingerprint collections. It takes account of the different patterns (arch, loop, whorl) and also depends on ridge counts between the core and delta of loops and whorls. The Henry system utilizes information from all ten fingers and consequently, a file cannot be searched for a single fingerprint. The Henry system also requires the classifier to recognize readily the basic patterns as well as cores and deltas. These recognition problems are serious obstacles in any effort to automate the Henry system.

The search for a suitable method for automatically scanning and classifying fingerprints has led to another aspect of fingerprint work: identification. Two fingerprints can be shown to belong to the same finger by comparing a few minutiae such as ridge endings, bifurcations or forks in ridges, incipient ridges, islands, and enclosures. Authorities generally regard the demonstration of 12 correspondences of minutiae (and of course no discordances) as proof that two prints originate from the same finger.² While the minutiae are distributed throughout the fingerprint, an identification can be made using the minutiae from any portion of the print. Thus a classification system using minutiae might even be used in searching for fingerprints corresponding to chance prints or latent prints where only a portion of the fingerprint is available. This paper describes a fingerprint identification system based on only two types of minutiae: ridge endings and bifurcations. There are about 93 such minutiae in the fingerprint shown in Figure 1. Four of these are labeled.

In the work reported in this paper the minutiae data are read manually. A set of descriptors is then computed and stored along with a label identifying the fingerprint on magnetic tape as shown in Figure 2. (A magnetic disc, drum, or other mass storage device could of course be substituted for the magnetic tape.)

After several sets of descriptors have been stored in the file, the file may be searched for a particular set of descriptors. The crux of the searching procedure is a matching program and Figure 2 illustrates the set-up used for experimenting with the matching program which is also described in this paper. An operator types in the identifying labels of two fingerprints that are known to be in the file. The matcher then reads the corresponding sets of descriptors from the file and computes a score, ST, which indicates how well the two sets match. The descriptors of a fingerprint can thus be compared with the descriptors of another fingerprint from the same or from a different finger. This paper does not deal with the problem of classifying and ordering the descriptors in the file for the purpose of minimizing search time.

2. Taking Minutia Data

Since a ridge ending in one fingerprint may appear as a bifurcation in another fingerprint from the same finger, no distinction is made between ridge endings and bifurcations in recording data. For each of these minutiae both a location and direction are defined as shown in Figure 3. If the areas marked B are considered as ridges, then point P is the location of a ridge ending and the line GP defines the direction of this minutia. If the areas marked A are considered as ridges, then point P is the location of a bifurcation, and the line GP defines the direction associated with this minutia. Hopefully, an automatic scanning device will soon be available which can scan a fingerprint and record the coordinates and directions of all of its minutiae.

In the work reported here, each fingerprint impression is photographed and enlarged by a factor of 10. The minutiae on each of these enlargements are then marked with a pencil on a piece of transparent plastic laid over the enlargement. Figure 4 shows the minutiae from an impression hereafter identified as II-W-1. Figure 5 shows minutiae from impression II-W-2 shown in Figure 1. Both impressions are from the same finger but were taken about two months apart. Each minutia is numbered for convenience in studying the identification system, but in an operating system the numbering is unnecessary.

Each transparency is next taped to a drawing board so that all minutiae markings fall in the first quadrant of an X-Y coordinate system as shown in Figure 6. The exact position is not critical. The X and Y coordinates of each minutia are then read in millimeters and recorded. The angle θ which the minutia direction makes with the X axis is recorded in degrees. Figure 7 shows a portion of this minutia data which is used for demonstrating this identification system. This is similar to the situation that would exist if only a part of the pattern were available in a latent fingerprint for searching against a fingerprint file. Note that the core and delta data are not needed in this system.

3. Computation of Descriptors

The complete logical details of the computer program for computing the descriptors that describe the impression are given in Flow Charts 1 through 5. A block diagram of the various steps is given in Figure 8.

The computer first reads in the identification and minutiae data for an impression such as that for impression II-W-1 shown in the left half of Figure 7.

3.1 Constellation Generator

As detailed in Flow Chart 1, each minutia point is taken as a focal point for a constellation of neighboring points. All points which are within a distance d of the focal point are considered for inclusion in the constellation. Each of those points is actually included in the constellation provided that its non-directed minutia angle (θ or $\theta-180$) differs by less than α degrees from the non-directed minutia angle (θ or $\theta-180$) of the focal point. Next, each point that is now in the constellation is in turn considered as a focal point and all data points are examined according to the above criteria to see if they too should be added to the constellation. However, all angles are compared to the minutia angle of the original focal point. As a result of the above procedure, minutia point 2 serves as a focal point for a constellation that includes points 2, 4, 5, and 8 as shown in Column E₁ in the left half of Figure 9. This constellation will hereafter be referred to as "constellation 2" in impression II-W-1 because it was formed about minutia 2 as a focal point. Constellations which do not include at least W minutiae points are rejected. Currently, $W=4$, $d=20\text{mm}$, and $\alpha=12^\circ$.

3.2 Constellation Selector

Since each minutia point takes its turn as a focal point trying to form a constellation, there will be some duplication of constellations. Accordingly, Flow Chart 2 details a procedure whereby any constellation that is equal to or included in another constellation is rejected. At the conclusion of the constellation generation and selection (Connector IV in Flow Chart 2), the data for impression II-W-1 in Figure 7 yields the four constellations shown at the left of Figure 9. Figure 9 also shows the two constellations that are generated from the data in Figure 7 for impression II-W-2.

3.3' Coordinate Transformer

Each constellation next undergoes a coordinate transformation. The center of gravity of the constellation is determined by computing the average value of the X and the average value of the Y coordinates. The coordinates X' and Y' of each point relative to this center of gravity are then computed as detailed in Flow Chart 3. The new coordinates for constellation 2 consisting of points 2, 4, 5, and 8 in impression II-W-1 are shown in Figure 10. Figure 10 also gives values for Z which is the direction of a minutia relative to the X axis. $Z=1$ means that the minutia points upward and $Z=0$ means that the minutia points downward. Z is readily determined from θ as shown in boxes 53 and 54 of Flow Chart 3. Figure 10 also gives the non-directed angle β of each minutia. If $\theta < 180$ then $\beta=\theta$. If $\theta \geq 180$ then $\beta=\theta-180$.

In the final step of the transformation, the coordinate axes are rotated so that the angle between the y axis and the initial X axis is equal to the average value of the angle β . In effect the y axis of the new coordinate system is aligned with the constellation. The coordinates of the minutiae in constellation 2 relative to this x - y coordinate system are shown in Figure 11.

3.4 Descriptor Generator

If the minutiae in constellation 2 are arranged in order according to the values of x and y in Figure 11, they can be exhibited on a grid as shown in Figure 12. The value of Z determines whether a minutia points up or down. The constellation is now in a measure-independent form. By comparing Figure 12 with the same minutiae in Figure 4 it will be seen that the minutiae have retained their positions and up-or-down directions relative to each other but distances between points and variations in the angles between minutiae have become irrelevant.

The descriptor $d_4 u_4 - d_3 u_3 - d_2 u_2 - d_1 u_1$ for constellation 2 is 10-01-12-03. This can be determined by inspecting Figure 12 as follows: d is the direction of the corresponding minutia and is equal to Z for this minutia. The value of u for each minutia is read from the scale along the Y axis. For example $d=1$ for minutia point 4 because 4 point upward and $u=2$ as read from the Y scale. The detailed procedure for this computation of descriptors is given in Flow Chart 4.

3.5 Descriptor Compression

It may be desirable to compress the information in a descriptor into a binary integer for the purpose of minimizing the amount of storage space that will be required in the file. One method for compressing a descriptor is illustrated in Figure 13. The right-most five bits contain the integer N, where N is the number of minutiae in the constellation. The next N bits to the left give the values of d_N, d_{N-1}, \dots, d_1 . The rest of the bits to the left represent the integer A whose derivation is described below.

Since the integers u_N, u_{N-1}, \dots, u_1 are a string of permuted numbers, there are $N!$ permutations of these numbers. Accordingly, each permutation can be identified with an integer A between 0 and $N!-1$ inclusive. For example, if $N=4$, each string of u 's can be related to a value of A as follows:

$u_4 u_3 u_2 u_1$	A
0 1 2 3	0
0 1 3 2	1
0 2 1 3	2
- - -	-
3 2 0 1	22
3 2 1 0	23

Flow Chart 5 gives a detailed procedure for computing the value of A corresponding to any given string of u's. This procedure, from the art of orderly listing permutations, is based on the lexicographical method of D.H. Lehmer.³ The total number of bits in the compressed descriptor is a function of N and this information may be utilized in packing the descriptors into the file. In the design of an automated fingerprint system the time needed for computing the compression and expansion of a descriptor must be weighed against the amount of file space that will be saved.

The four descriptors for impression II-W-1 and the two descriptors for impression II-W-2, shown in Figure 14, result from the data shown in Figure 7. The compressed forms of these descriptors are shown as octal integers for convenience. The impression identification name (Ident) II-W-1 and its set of four descriptors are now written in the electronic file as shown in Figure 2. A similar procedure is carried out for impression II-W-2 and, of course, the descriptors for other fingerprint impressions may also be placed in the file. In a practical application of this system it would be undesirable to store the identifying name (Ident) in the file. Instead the filing computer might supply a number to the fingerprint reader which is a unique function of the location in the file where the fingerprint descriptor is stored. This number would be written on the fingerprint card and would become the serial number which determines where the fingerprint card is filed.

4. Matching Fingerprint Descriptors

The matcher shown at the right in Figure 2 is used for studying the effectiveness of the descriptor design. Descriptor sets for two different fingerprint impressions in the file, named IdentA and IdentB, are read from the file and compared. A score ST is printed by the computer indicating how well the descriptors match. The impressions being compared may be from the same or different fingers and, of course, the score ST should be high if the impressions are from the same finger and low if the impressions are from different fingers. Various parameters in the descriptor generator such as d=distance between minutiae, α =angle between minutiae directions, and W=minimum number of minutiae required to form a constellation can be varied while the resulting score ST is observed. The next section describes one of several experimental methods for matching descriptors.

4.1 Descriptor Expansion and Elaboration

An operator typing in two identifying impression names such as II-W-1 and II-W-2 will cause the computer to retrieve the set of compressed descriptors corresponding to each of these impressions. Each compressed descriptor is then expanded into its original form by the inverse of the procedure illustrated in Figure 13. The permuted numbers are generated from the integer A by the procedure detailed in Flow Chart 6.

Assume now that the computer contains the two sets of descriptors shown in Figure 14. The computer will next proceed to compare each descriptor of impression II-W-1 with each descriptor of impression II-W-2 and accumulate a score ST as it proceeds. The comparison of the descriptor for constellation 41 in impression II-W-1 with constellation 41 in impression II-W-2 will be used in explaining the procedure. The pictographs for these constellations are shown in Figure 15. The minutiae are compared from right-to-left. They are also compared from top-to-bottom, and to facilitate the latter comparison, a second descriptor is computed for each constellation. If a pictograph in Figure 15 is rotated 90° clockwise, the new descriptor $e_4^v e_3^v e_2^v e_1^v$ is derived in the same way that was described earlier in this paper in the section labeled Descriptor Generator. However, now each direction bit $e=1$ if the minutiae points to the right and $e=0$ if the minutia points to the left. The resulting descriptors are shown at the right of each pictograph in Figure 15 and the details of their computation are given in Boxes 6, 7, and 8 in Flow Chart 7.

The minutiae in each pair of constellations such as those shown in Figure 15 are next compared three at-a-time working from right-to-left and also from top-to-bottom. The method for accomplishing this is illustrated by grouping the minutiae in 3x3 pictographs working from left-to-right. This is illustrated in Figure 16 for constellation 41 of impression II-W-1. The direction bits are converted to octal equivalents (reading backward) and the permutations are converted to their ordered-list equivalents as described earlier in the section on Descriptor Compression. For convenience in hand calculation, the following conversion table can be used.

<u>Permutation</u>	<u>a</u>
210	0
120	1
201	2
021	3
102	4
012	5

The details for computing the horizontal triads $a_{N-2} b_{N-2} \dots a_1 b_1$ from the descriptor $d_{N,N}^u \dots d_{1,1}^u$ and the vertical triads $f_{N-2} g_{N-2} \dots f_1 g_1$, from the rotated descriptor $e_{N,N}^v \dots e_{1,1}^v$ are given in Boxes 9-23 in Flow Chart 7. The results for the illustrative example are given in Figure 17.

4.2 Triad Matching

For each pair of constellations being matched, each ab triad in the first constellation is compared with each ab triad in the second constellation. When two of these triads are found to be equal, a score S is set equal to 1 and the next successive triads from the constellations are compared. If these are found to be equal the score is increased by 1. This procedure is repeated until either string of triads is exhausted. The score S resulting from this run of matches is compared with the score resulting from any other run of matches that may occur for the same pair of ab strings. The largest of these scores is designated S1. Matching the two ab strings in Figure 17 results in only one run and the final score is S1=3. The details for this computation are given in Flow Chart 8.

The two fg strings from the same pair of constellations are next matched as described above. The score for the example in Figure 17 is S2=2. The total score for the constellation match is SS=S1+S2, and SS=5 in the example. Any score SS that is equal to or greater than a threshold score SL is retained and all others are rejected. In a practical application of this identification system the parameter SL might be set low when searching for latent fingerprints and be set higher when searching for regular fingerprints.

The total score ST resulting from matching two impressions is equal to the sum of all SS scores resulting from matching the various pairs of constellations from the two impressions. The scores resulting from matching the two impression fragments whose minutiae data is given in Figure 7 are shown in Figure 18. The total score, ST=8, includes two legitimate constellation matches (41-41 and 40-41) producing a total score of 6 and a false match (40-2) producing a score of 2. False matches produce a certain amount of "noise" in the score and it may be desirable to reduce this noise by filtering.

5. Conclusions

Complete sets of descriptors have been computed for a few fingerprint impressions from the same and different fingers. The parameters used were $d=20\text{mm}$, $\alpha=12^\circ$, and $W=4$. When the descriptors for two impressions from different fingers were compared, the score SS resulting from comparing pairs of constellations was found to occasionally have values of 1, 2, or 3 but seldom more than 3. Most of these scores, indicating false matches or noise, were therefore eliminated from the accumulated score ST by setting the parameter $SL=4$ in the matcher program. Then a further improvement in scoring was found by defining a new score SK equal to the score ST with $SL=4$ divided by the score ST with $SL=1$. The SK scores resulting from comparing various pairs of impressions from the same finger were found to be generally higher than SK scores resulting from comparing the impressions from different fingers.

Based on the limited amount of fingerprint data processed to date, the procedure described in this paper offers promise as a basis for a single-fingerprint classification system. Many more fingerprint impressions must be processed, and optimum values must be found for the various parameters corresponding to the characteristics of the minutia reader used. Also, a method of ordering the descriptor sets is needed so that fingerprints can be classified and filed in a manner that will minimize search time. It may be possible to further reduce the amount of information filed in the descriptors and further improvement may be possible in the matcher. For example, matching quads instead of triads may offer some advantage. Finally, the computer time required for matching must be reduced to the lowest possible value.

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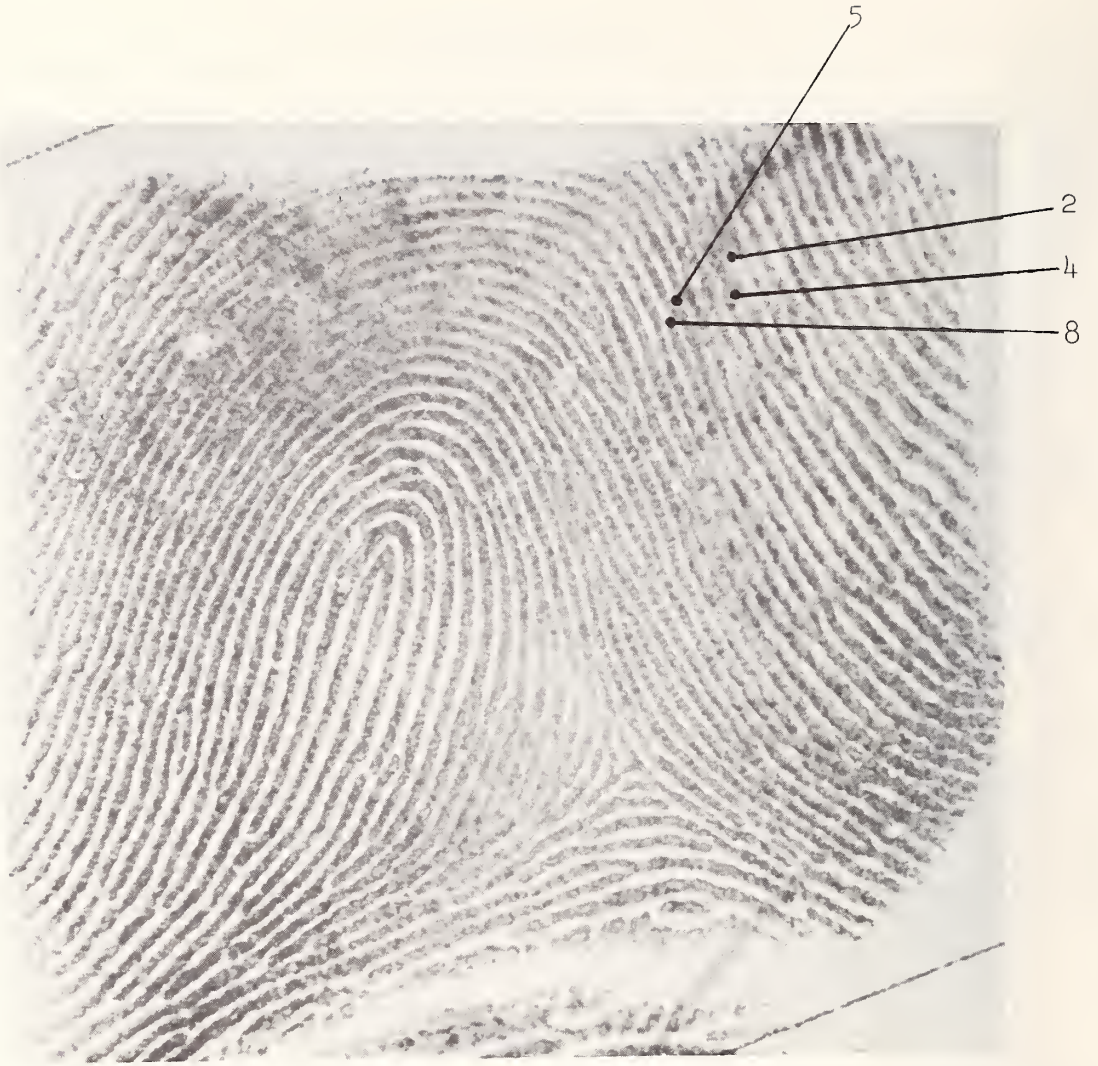


Figure 1 -- Fingerprint Impression II-W-2

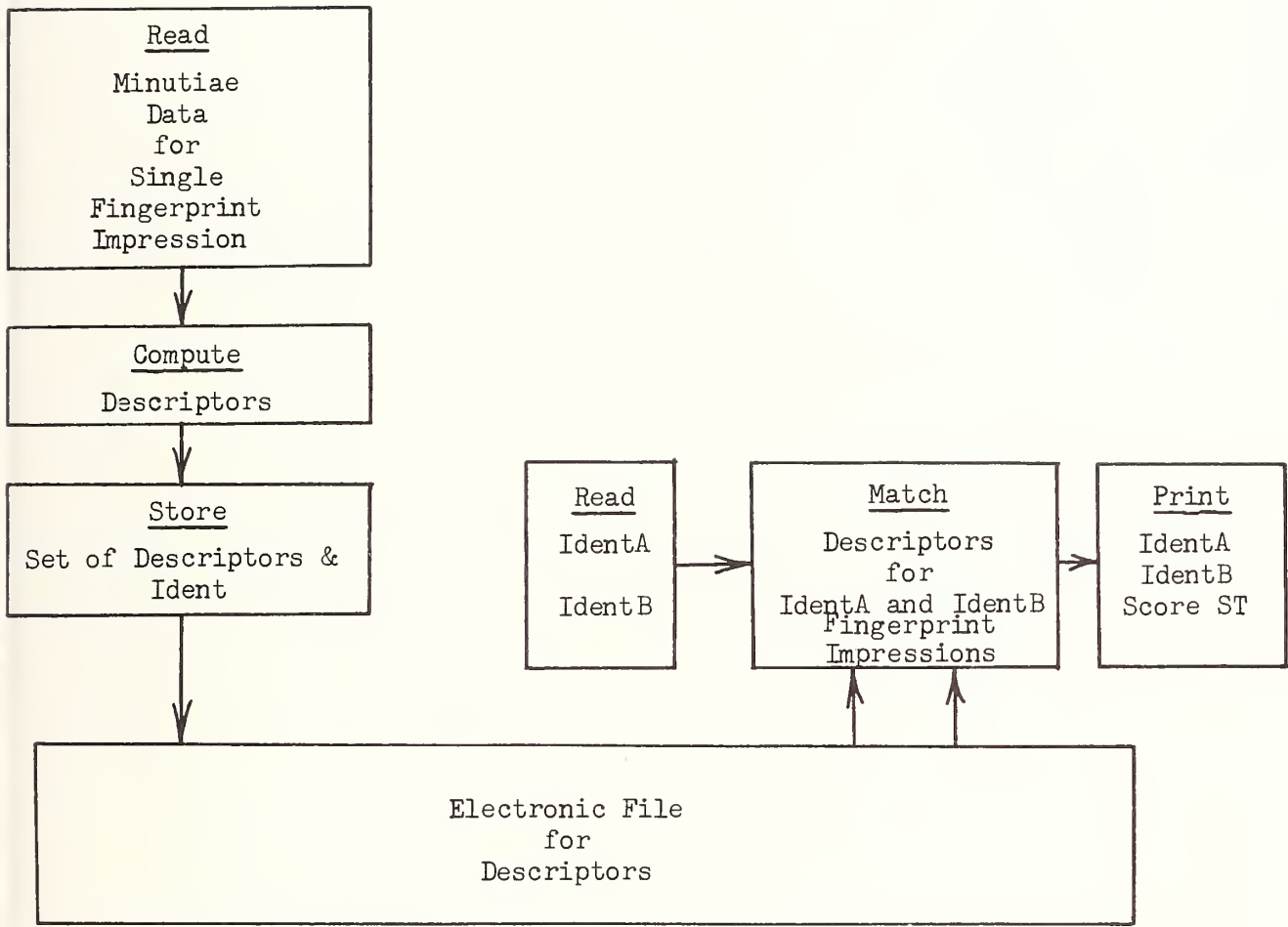


Figure 2 — Computerized system for experimentally identifying fingerprints

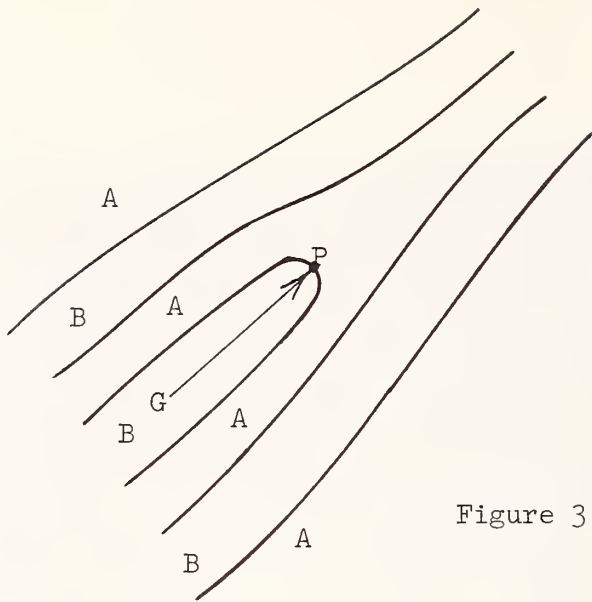


Figure 3 -- Location and direction of a minutia.

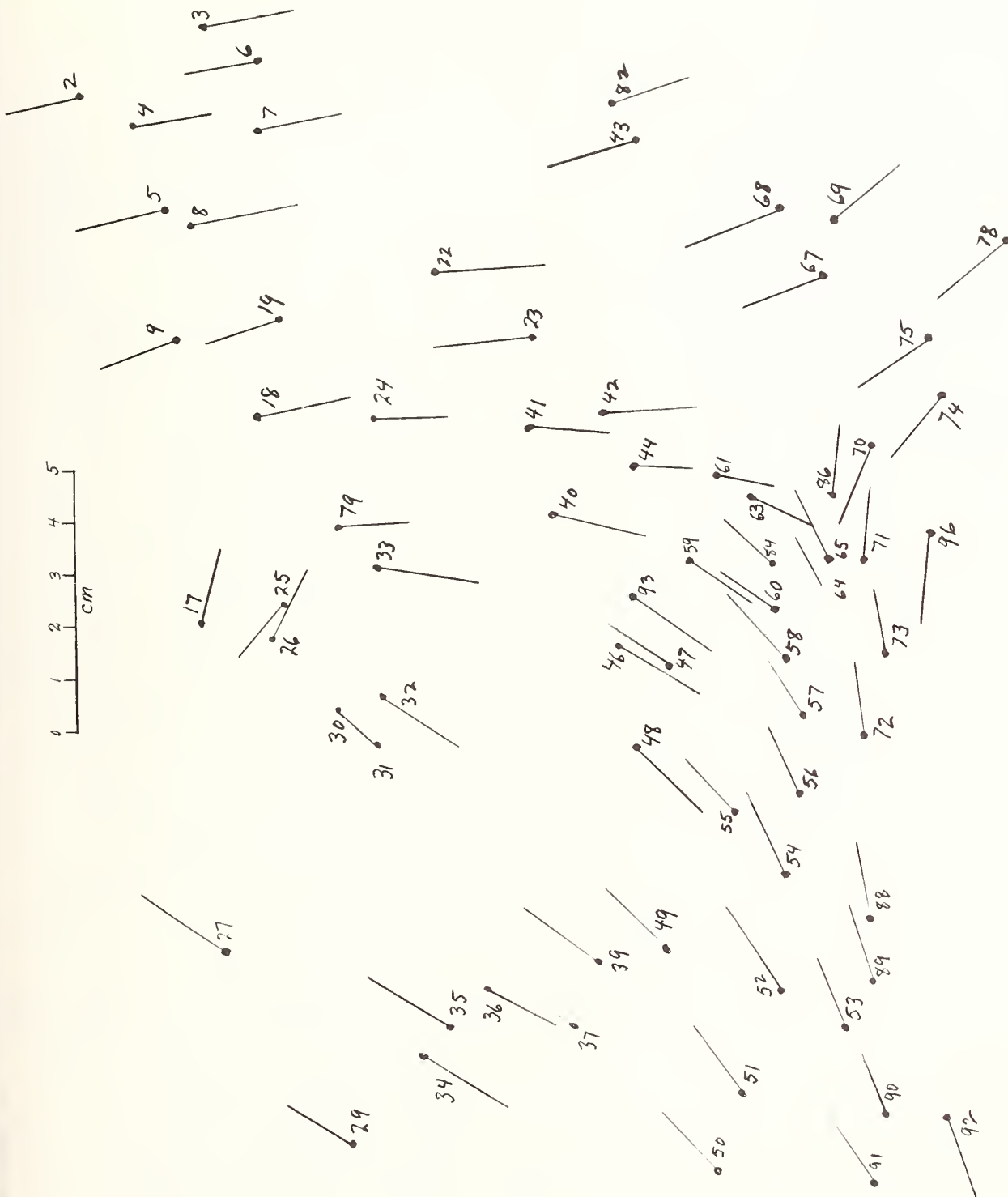


Figure 4 -- Minutiae from impression II-W-1

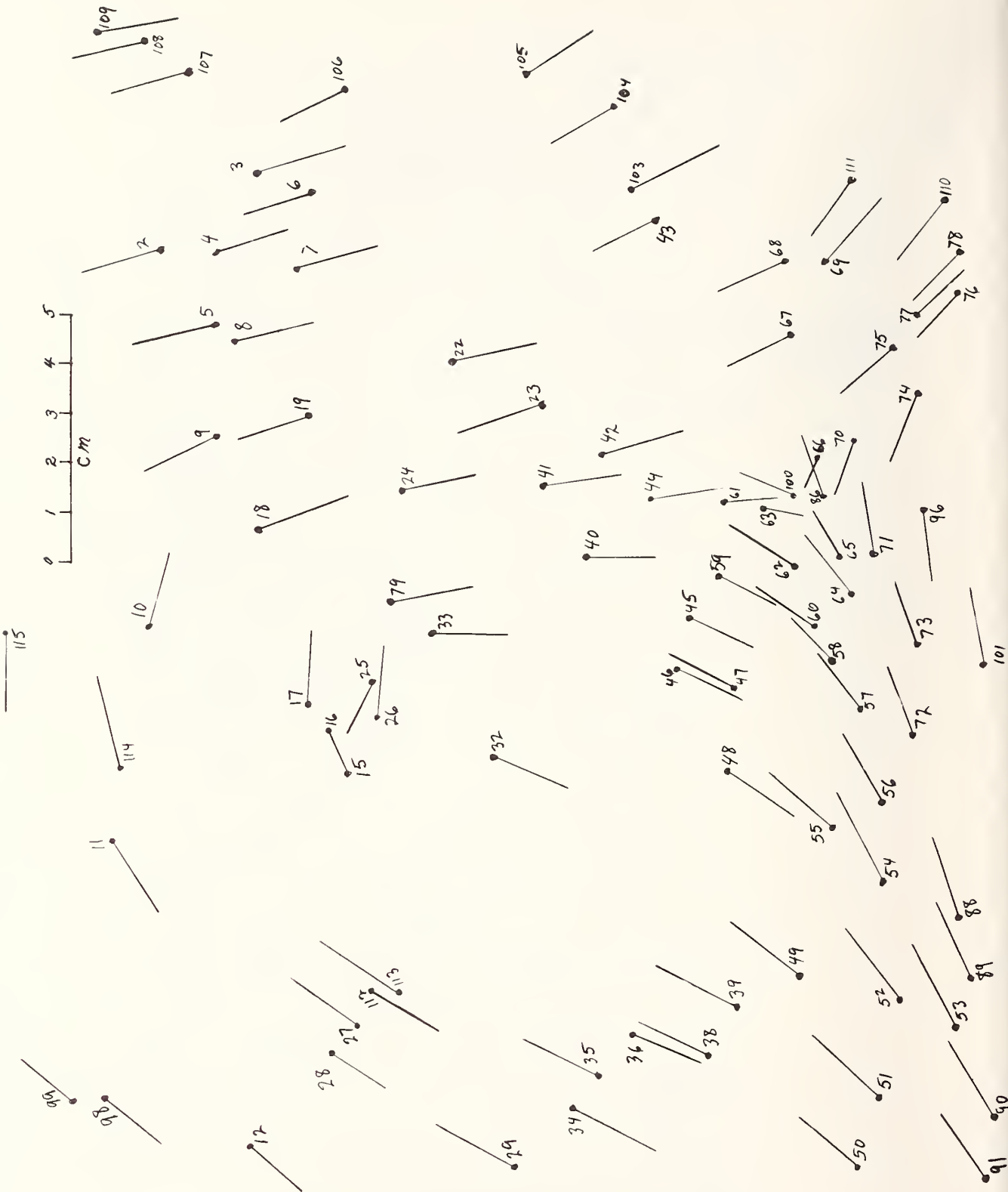
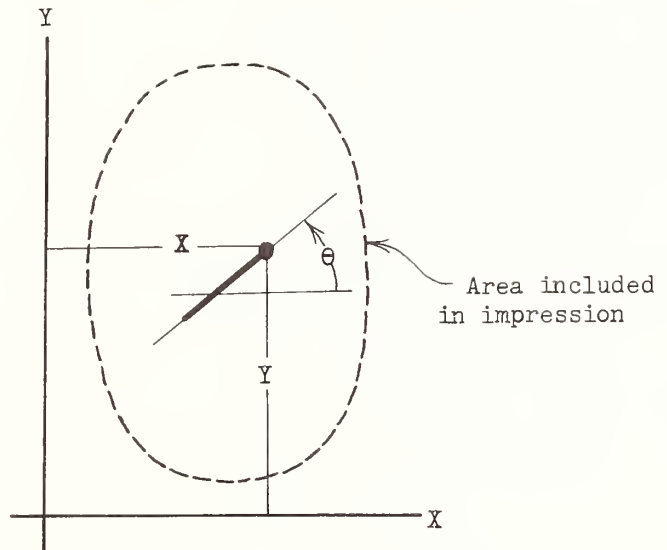


Figure 5 -- Minutiae from impression II-W-2

Data Recorded			
Point Number	X in mm.	Y in mm.	θ in degrees

Figure 6 — Method used for recording minutiae data



Fingerprint Impression II-W-1

Fingerprint Impression II-W-2

p	X	Y	θ
2	203	221	293
3	221	200	101
4	200	210	110
5	185	201	294
6	216	188	290
7	203	186	111
8	183	195	112
9	161	194	301
22	183	148	104
23	174	127	287
40	142	117	87
41	157	125	95
42	163	111	104
43	215	115	298
44	154	103	97
61	155	088	89
63	152	080	75
53	051	044	213
88	078	043	202
89	066	041	209
90	042	033	214
92	043	022	30

p	X	Y	θ
2	199	208	290
3	216	190	110
4	200	197	111
5	185	196	287
6	213	179	291
7	197	181	109
8	182	192	107
23	173	129	293
40	143	118	94
41	156	128	102
42	164	116	110
44	156	106	102
61	156	091	98

Figure 7 — A portion of minutiae data used for demonstrating descriptor generation and matching

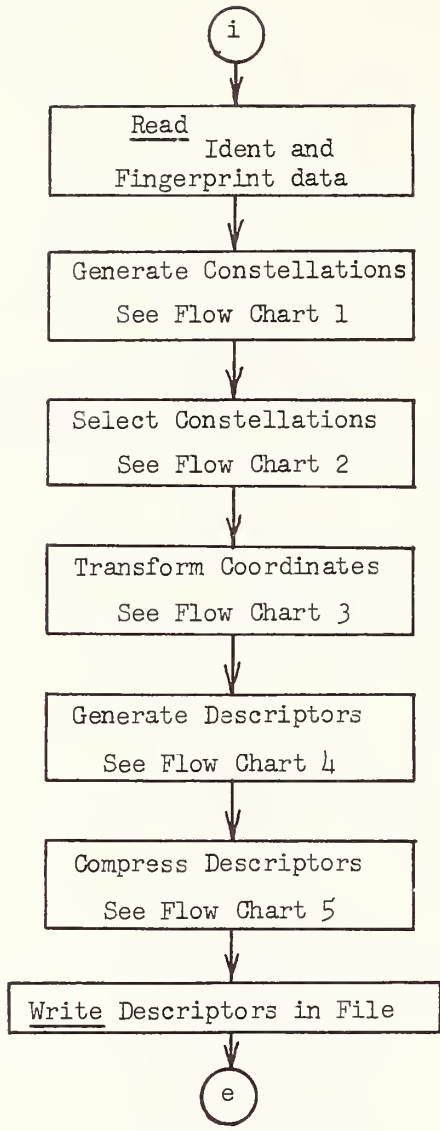


Figure 8 — Computation of Descriptors

Fingerprint Impression II-W-1				Fingerprint Impression II-W-2	
\bar{E}_1	\bar{E}_2	\bar{E}_3	\bar{E}_4	\bar{E}_1	\bar{E}_2
2	41	40	53	2	23
4	23	41	89	4	41
5	40	44	90	5	42
8	42	61	88	3	40
	44	63	92	7	44
	61			8	61
				6	

Figure 9 — Constellations Selected

Impression II-W-1

Constellation 2

p	X'	Y'	Z	θ
2	10.25	14.25	0	113
4	7.25	3.25	1	110
5	-7.75	-5.75	0	114
8	-9.75	-11.75	1	112

Figure 10 -- Minutiae, coordinates, and directions relative to coordinate axes at constellation's center of gravity

Impression II-W-1

Constellation 2

p	x	y	z
2	14.88	9.30	0
4	7.94	.26	1
5	-9.35	-2.38	0
8	-13.47	-7.17	1

Figure 11 -- Minutiae coordinates relative to rotated axes.

Impression II-W-1
Constellation 2

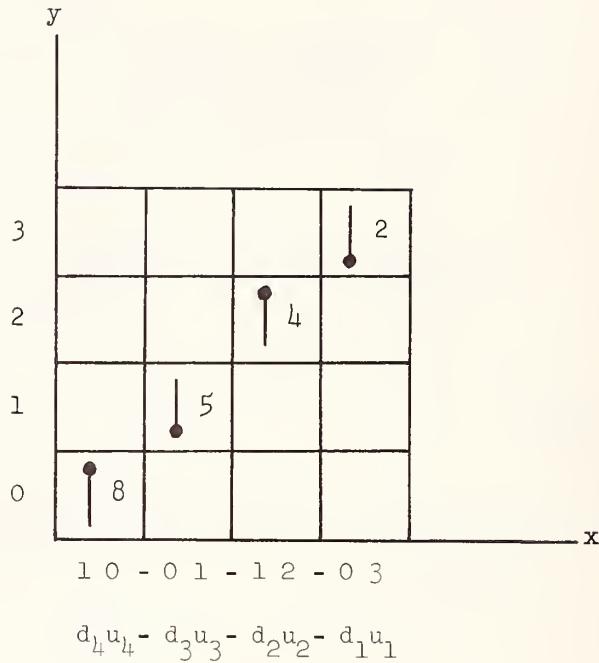


Figure 12 — Measure-independent constellation and resultant descriptor

Impression II-W-1
Constellation 2

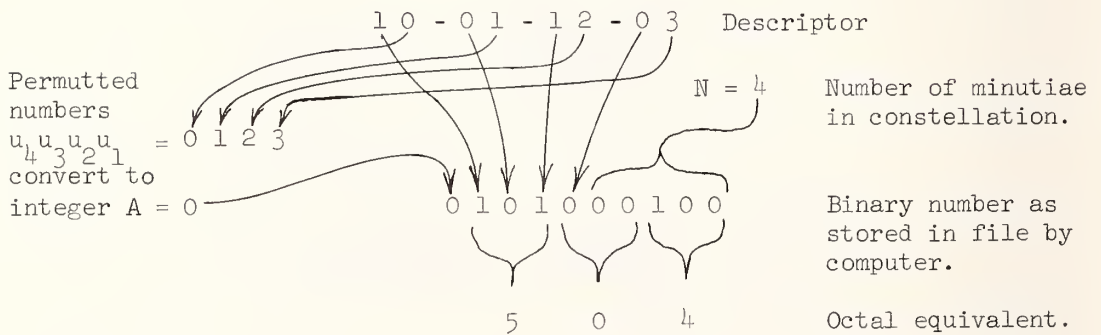


Figure 13 -- Compression of descriptor for storage in electronic file

<u>Impression II-W-1</u>			
<u>Constellation</u>	<u>Minutiae in Constellation</u>	<u>Descriptor</u>	<u>Octal Form of Compressed Descriptor</u>
2	8,5,4,2	10-01-12-03	504
41	40,61,44,41,42,23	13-10-11-14-12-05	2653706
40	40,63,44,61,41	13-10-12-11-14	225745
53	53,88,89,90,92	02-01-03-04-10	162045
<u>Impression II-W-2</u>			
2	8,5,7,4,2,6,3	14-05-11-13-06-00-12	65105447
41	40,61,44,41,42,23	13-10-11-15-12-04	2663706

Figure 14 — Descriptors corresponding to fingerprint shown in Figure 7

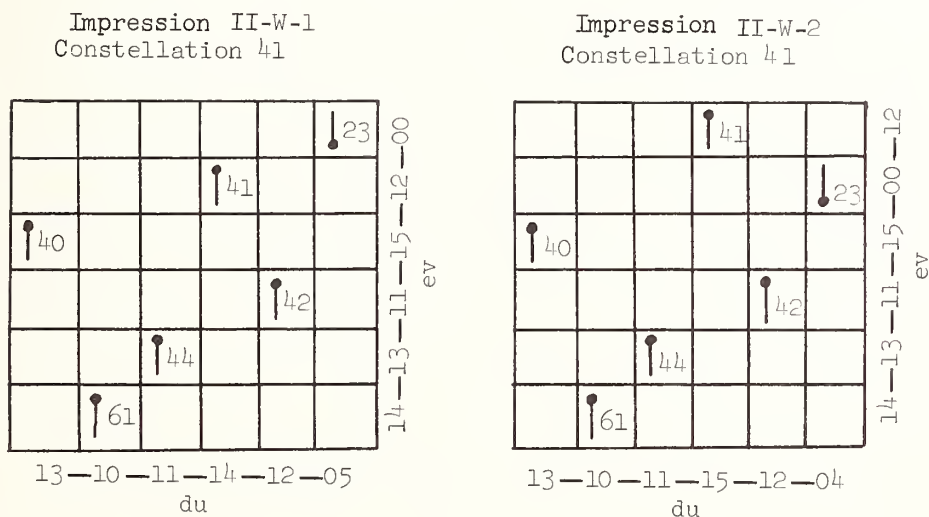


Figure 15 — Pictographs of the same constellation from two different fingerprint impressions

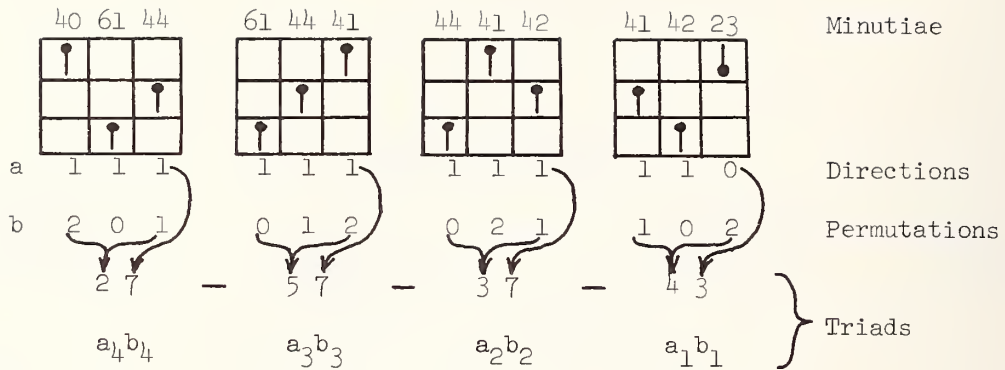


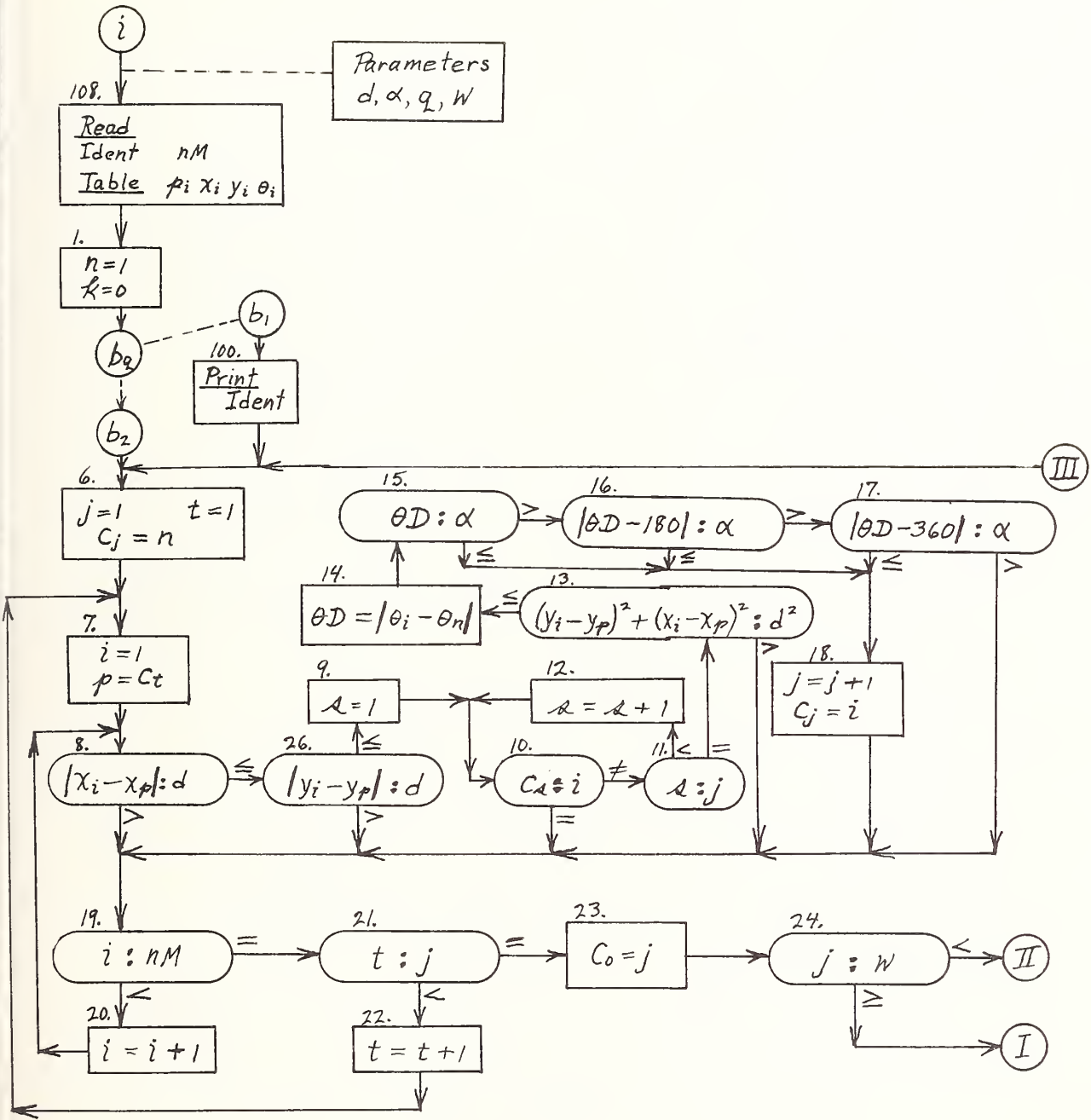
Figure 16 — Derivation of horizontal triads for constellation 41 in fingerprint impression II-W-1

	Impression II-W-1 Constellation 41		Impression II-W-2 Constellation 41	
	Horizontal	Vertical	Horizontal	Vertical
Descriptors	du 13-10-11-14-12-05	ev 14-13-11-15-12-00	du 13-10-11-15-12-04	ev 14-13-11-15-00-12
Triads	ab 27-57-37-43	fg 07-47-37-03	ab 27-57-37-23	fg 07-47-13-25

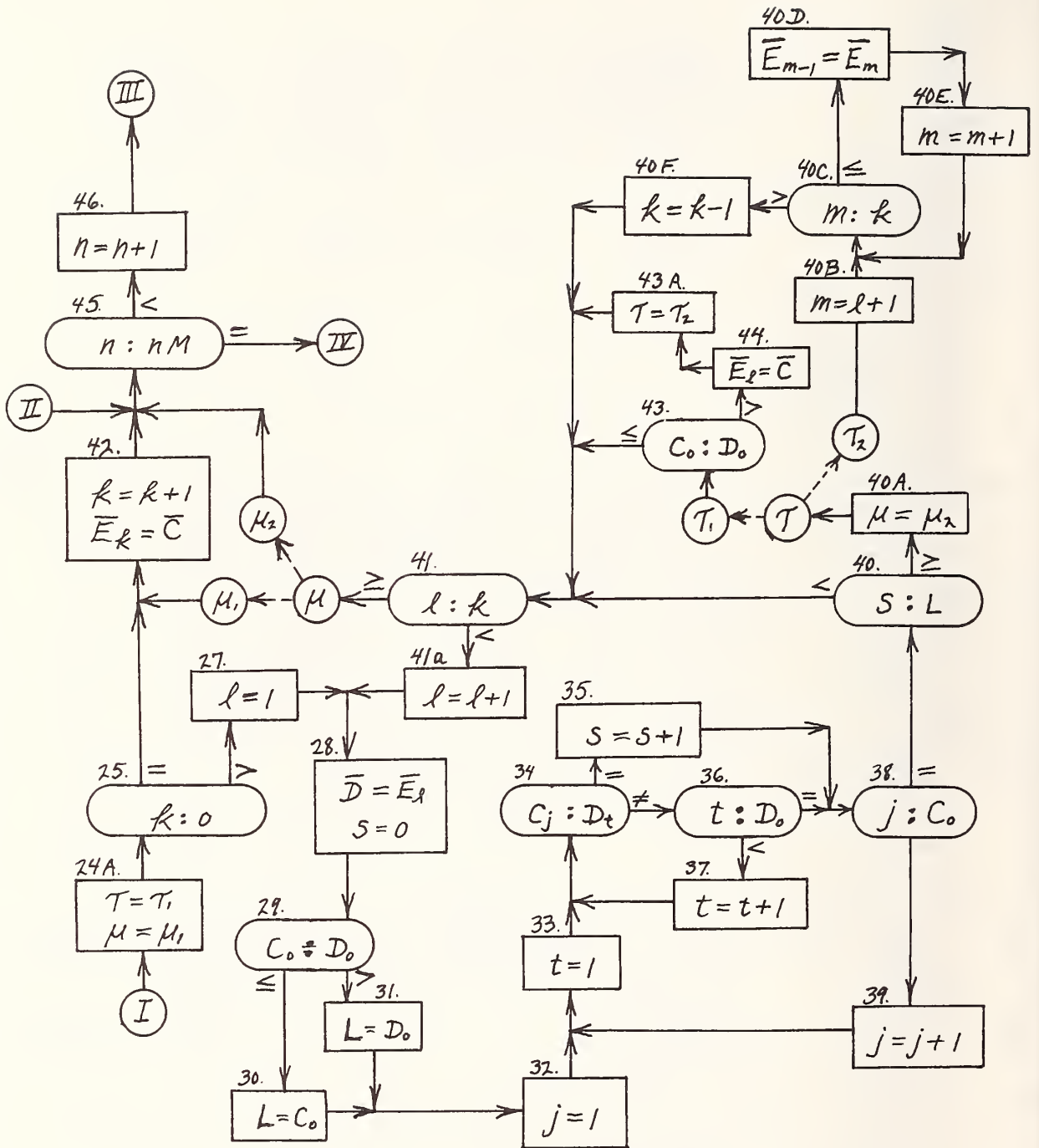
Figure 17 — Descriptor and triad data for illustrative example

Impression II-W-1 <u>Constellation</u>	Impression II-W-2 <u>Constellation</u>	Score for Constellations		
		<u>S1</u>	<u>S2</u>	<u>SS</u>
41	41	3	2	5
40	2	0	2	2
40	41	1	0	1
Total Score			ST = 8	

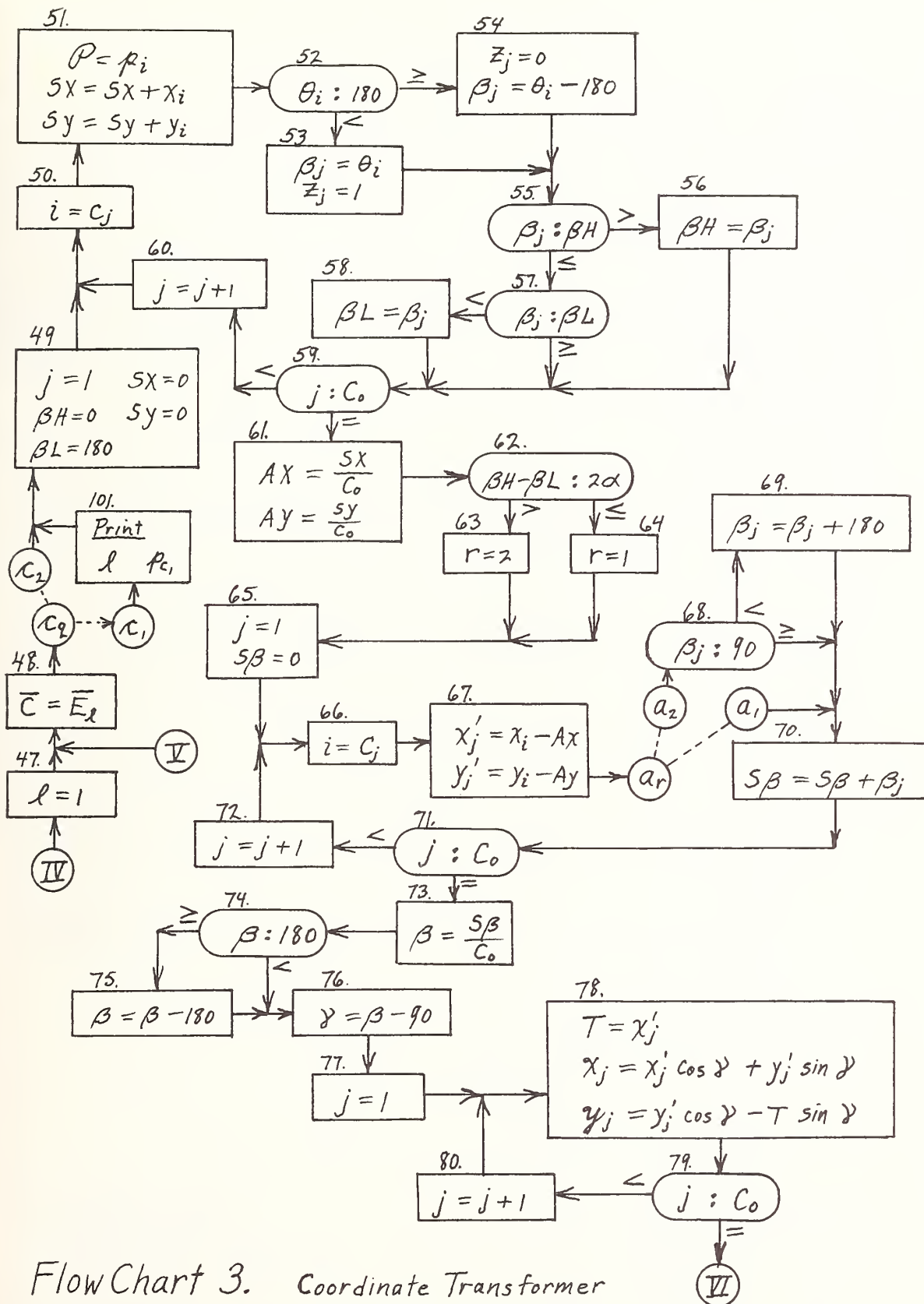
Figure 18 — Score resulting from matching Impression II-W-1 with Impression II-W-2



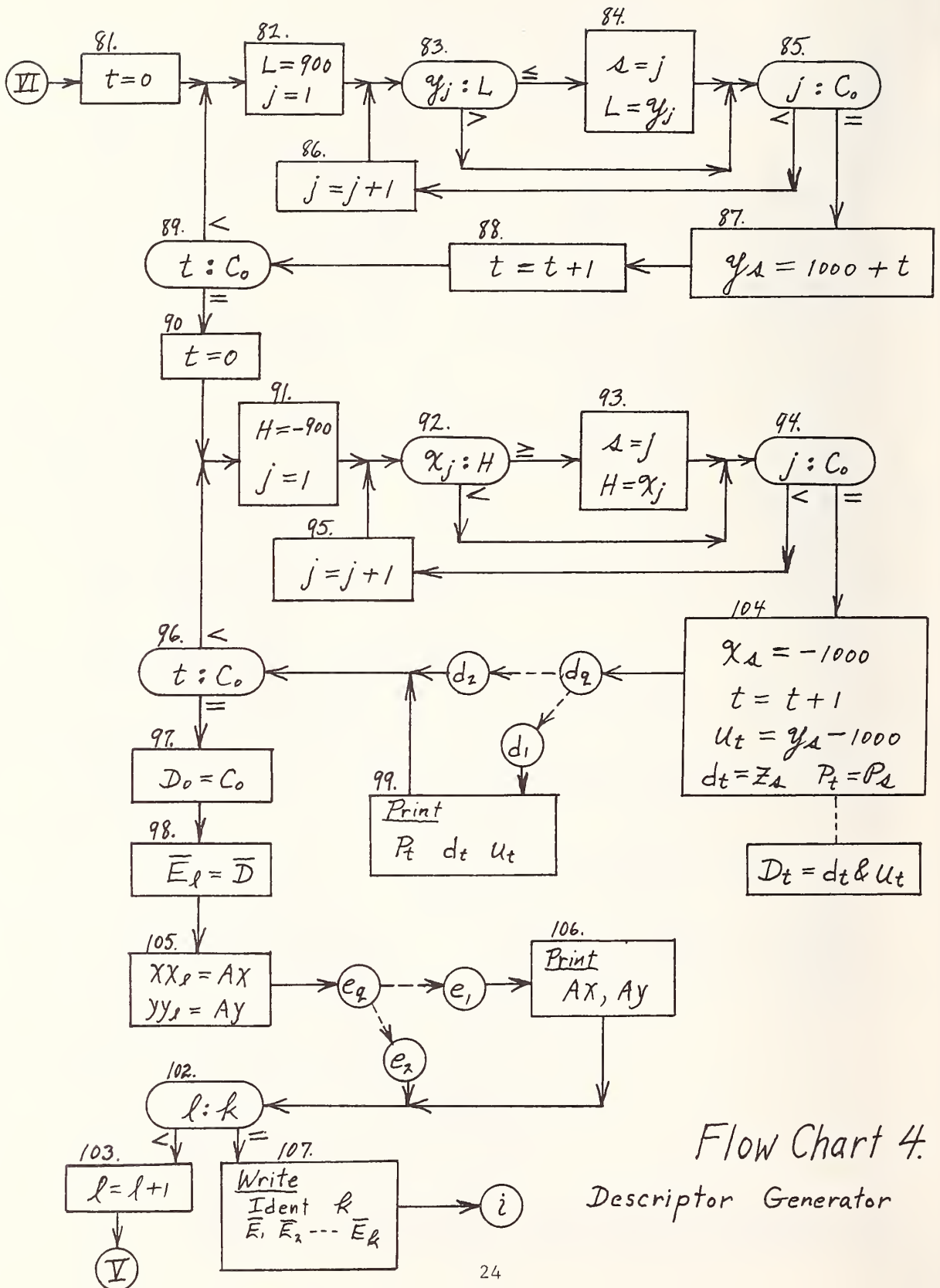
Flow Chart 1. Constellation Generator



FlowChart 2. Constellation Selector

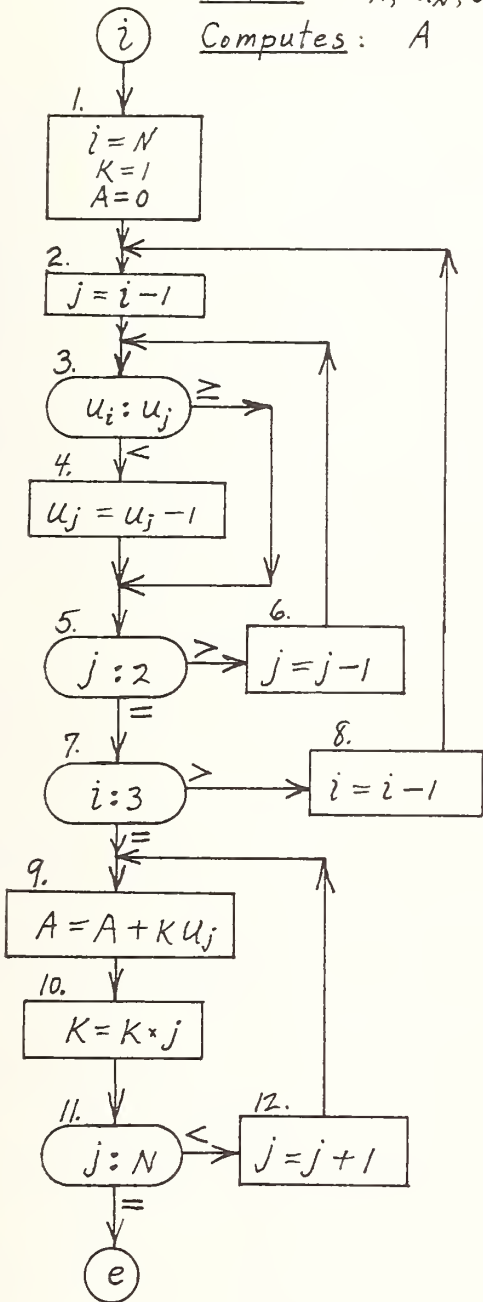


FlowChart 3. Coordinate Transformer



Flow Chart 4.
Descriptor Generator

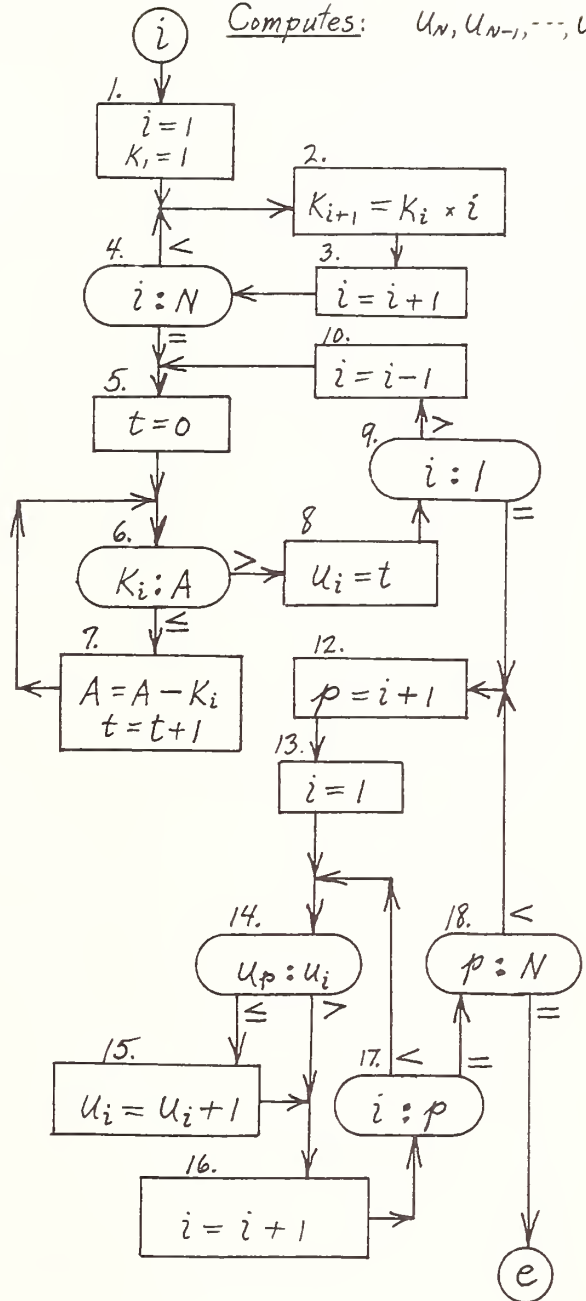
Given: $N, u_N, u_{N-1}, \dots, u_1$
 Computes: A



Flow Chart 5.

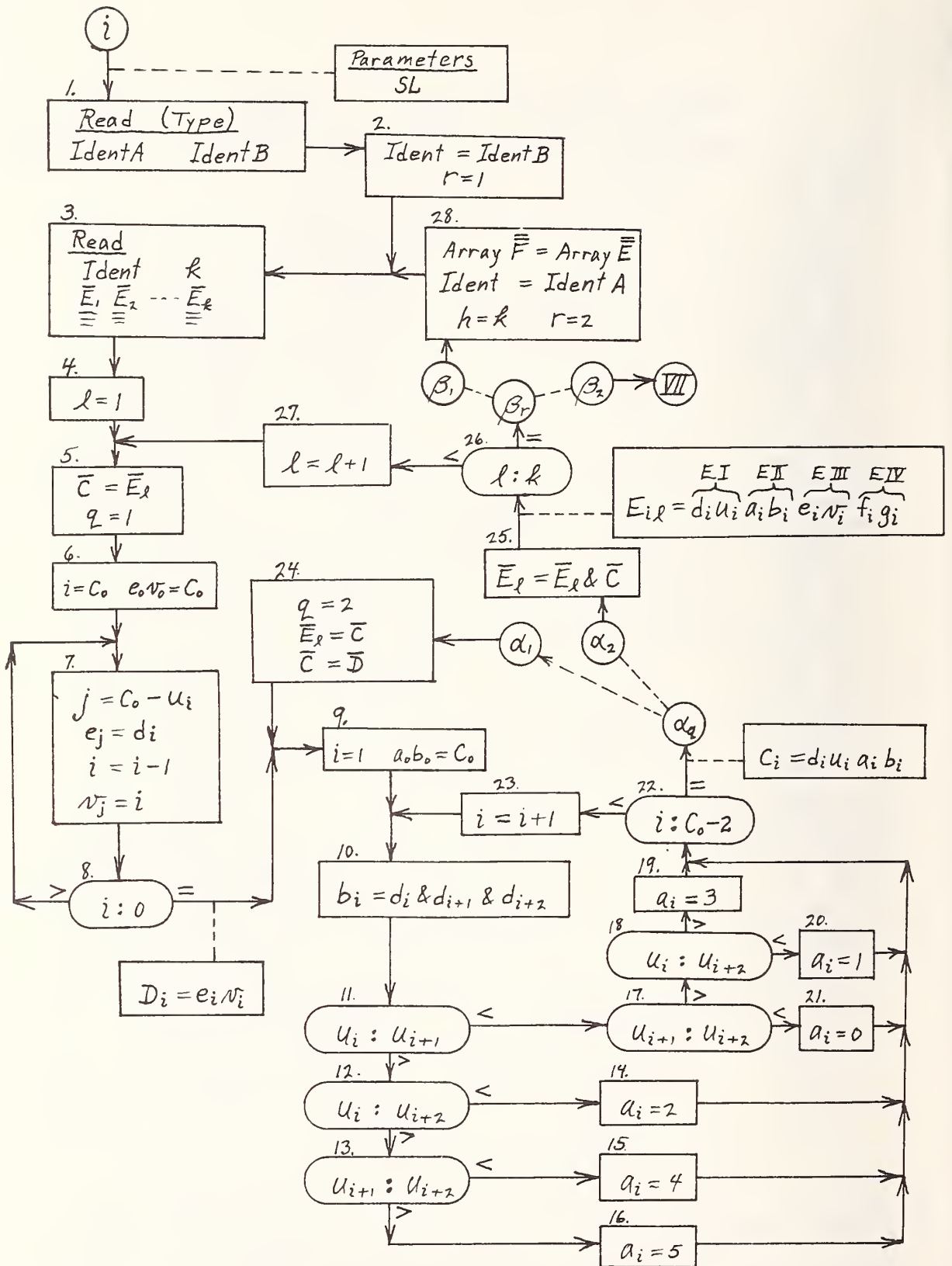
Compressor

Given: N, A
 Computes: u_N, u_{N-1}, \dots, u_1

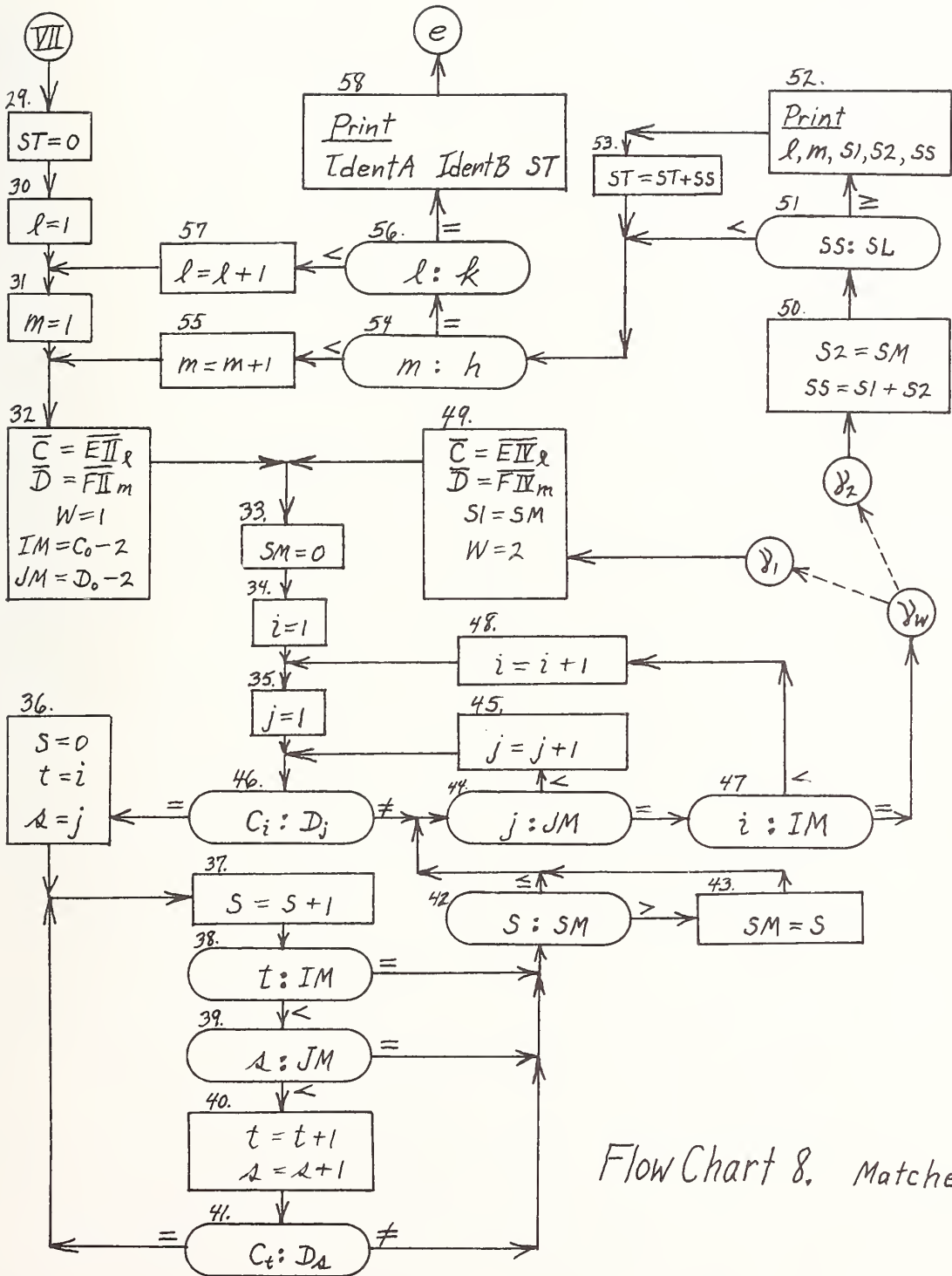


Flow Chart 6.

Expander



Flow Chart 7. Triad Generator



Flow Chart 8. Matcher



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