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A proposal for analogue cum digital character recognition.

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A PROPOSAL FOR ANALOGUE CUM DIGITAL CHARACTER RECOGNITION

BY

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ABSTRACT

An analogue-digital device for the recognition of hand printed capital block letters and numerals is proposed. The unknown characters are projected onto a grid of photo-diodes. The edges and corners of the character are then emphasized by a detail filter and the output voltages of the diodes are normalized. Each of the 36 characters is placed in one of four subsets to reduce the number of samples required for identification. Then the characters are examined for the presence or absence of eighteen characteristics. Up to this stage the operation has been analogue in nature but since a large memory capacity is required the operation is transferred to an on-line digital computer.

The computer operates on the above information. The analogue signals are quantized and codes for each character are established during the learning phase of the computer programme. During the testing or identification stage the computer programme employs three criteria to identify the unknown presented on the grid of photo-diodes.

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CHAPTER 1

INTRODUCTION

In this analysis the problem of automatic recognition of a line pattern by a machine will be discussed. The various types of patterns identified by many recognition devices include visual, aural and electromagnetic patterns. Due to the demands of high speed data processing the majority of work done on pattern recognition has been in the visual field and specifically concerned with the identification of spatial characters.

In recent years this problem has attracted an ever increasing number of investigators as may be seen by the large number of papers written on automatic pattern recognition, especially automatic character recognition devices. All the investigators ignore such properties as colour, texture, gradations of shading, motion, overall light intensity and three-dimensionality. Although research has been confined to the narrow area of two dimensional character sets there are still many unsolved problems requiring investigation. Amongst these is that of the topographical variations of the patterns. This is the property, possessed by humans, to properly classify poorly formed patterns. Another one is that of noise. There are two kinds of noise: (i) dust spots, smudges, granularity and background intensity variations; (ii) that characterized by the signal element itself, i.e. such things as gapped lines, extra serifs and flourishes etc. A third consideration is that of having the system flexible enough to accept and identify patterns in a non-standard position or of a non-standard size. There will, of course, have to be certain limits placed on the extent of departure from the standard. Another problem requiring investigation is that of the rotation of the patterns.

1.1 Historical Review *

The complexity of the character recognition problem has generated many diverse solutions. Due to this large number a detailed categorization is difficult but certain broad divisions can be made. Among these is the distinction between the self-organizing and the programmed-decision approaches. The concept of a self-organizing system was first brought to wide scientific attention by Ashby(2) in 1952 when he was considering the basic problems of automata, chess-playing machines and other similar devices. In a later classic paper Ashby(3) discussed what he called an "intelligence amplifier" (one intellectual predecessor of the present self-organizing system). Here Ashby presented the idea that the problem of intelligence is

* This section is essentially a summary of a survey presented by Spinard(1) in the introduction to his doctoral thesis.

not one of the creation of ideas but rather that of the selection of valid ones from an essentially random collection of relationships. He proposed that codes, interpretable as ideas, be generated at random and be tested against the known constraints and the data of the problem situation. Only when a satisfactory "fit" was obtained could the random generator be turned off and the "satisfactory" set of relationships would then be called the solution. Ashby called his device a "homeostat".

Selfridge[(4)], in 1956, proposed the application of the homeostat concept directly to the pattern recognition problem. He went somewhat further in asking for a self-organizing choice of the selection criteria. In 1958, Rosenblatt[(5)] published a massive report describing the structure of a self-organizing pattern recognizer which he called the "Perceptron". The Perceptron analyzed spatial patterns by first quantizing them into black or white elements in a discrete array. Then random sets of elements were examined as to their overlap with the patterns to be identified. The greater the degree of overlap the greater the weight assigned to the set. Sets of these sets were then formed and assigned to a particular input pattern. A series of variations on the ideal pattern were then presented. After each presentation, the weights assigned to each subset were adjusted to reflect the pertinence they retained to the "identification" of the input pattern. A series of exposures and adjustments constituted the "learning" phase. For every different "ideal" pattern, separate sets were formed and weighted. After all the patterns were "learned" an unknown was presented. The identification of the unknown was accomplished by determining which of the unknown sets it best conformed to.

Uhr and Vossler[6] developed the self-organizing technique to the point where they simulated, on a digital computer, a device that generates, evaluates and adjusts its own operation.

The fault of all of the self-organizing system approaches is that they concentrate on the details of their adjustable internal structure and almost neglect the nature of the input stimuli. The remainder of the workers reverse the above situation and focus their attention on the input stimuli while essentially neglecting the internal structure of the device.

The next broad group of workers are those who employ a standard set of masks and attempt recognition on the basis of matching the unknown with the masks. These works are characterized by the assumption that if the input character is to be recognized then a high degree of overlap with a standard character must be present. The pioneer paper in this group was presented by Uttley[7] in 1956.

Marril and Green[8] and Highleyman[9] analyzed the situation where the probability distribution function on the input plane for every character is assumed known. They derive formalisms for making the maximum likelihood decisions as to the identity of the unknown.

Anotner approach was to classify patterns not so much by their overlapping areas as by the identification of certain salient features such as corners, enclosed regions, cusps and straight lines. In common with the previously described approach this one also quantizes the pattern into a discrete black and white spatial array.

Another interesting approach is that taken by Sprick and Ganzhorn(10). They used the time derivatives of spatial contours to generate identifying and distinguishing characteristics. They applied their technique to the ten numerals but their quantitative results were not clear from their paper.

Unger(11,12) proposes an entirely different approach. He argues that the way to treat data that is generated in arrays is with a computer that manipulates the arrays directly. The registers in this computer are two dimensional arrays. The order code structure contains orders like: "link", "expand" and "shift around" in addition to the more basic ones. In reference (11) he describes the operation of a programme for his spatial computer as simulated on an ordinary digital computer. The fact that this programme can be simulated on a digital computer defeats its own purpose.

A completely topological technique was reported by Ming-Kuei Hu(13). He suggested processing the pattern to form the first, second, third and higher order moments. He claims that a distinctive character sort can be made using these moments but he does not report any results.

As the field continues to grow towards maturity some workers are examining the various proposed decision techniques more analytically. Highleyman[14,15], for example, examines linear decision functions, their relationship to other selection processes, and their relevance to the pattern recognition problem. Marril and Green[16] developed tests of the quality of a set of measurements on a pattern which, to some extent, anticipate the pragmatic results of an unknown set.

Recent work has tended to show a greater emphasis on pattern measurements which are more realistic than those based on the simple assumptions of statistical independence between mask elements. Chow[17,18] has treated the effects of neighbour dependence in the element masks.

All of the work discussed thus far has been done on a digital computer or is completely digital in nature. This fact has both its advantages and disadvantages. Due to the sequential nature of digital devices they are relatively slow as compared to the parallel operation of an analogue device. The digital machine usually requires a quantization of the data into discrete bits which results in a loss of a great portion of the information present in the signal. The greatest advantage of this mode of operation is the large memory capacity as millions of bits of information, accessible in microseconds, are available to the programmer. Flexibility in operation of the digital computer allows one to change the selection criteria of the decision process, an advantage not possessed by the analogue device.

Because of the disadvantages noted above a few workers have turned to a completely analogue device for the recognition of patterns. Taylor[19] employs simple addition units to extract information from the input signals and does not quantize the signal until the last possible moment. However, the memory scheme that he employs is rather crude and there is little flexibility in his recognition device.

In addition to a purely analogue device many workers have built devices employing the advantages of the digital as well as the analogue techniques. Nadler[20] employs several analogue techniques but the majority of his work is digital in nature.

1.2 Proposed Recognition Scheme for Block Letters and Arabic Numerals

It can be seen from the above survey that the problem of automatic character recognition may be divided into two subsiduary problems; (i) what properties of the pattern should be measured, (ii) how should the measurements be processed in order to arrive at a decision about the identity of the pattern. Each of the problems is equally important and difficult and the success of any pattern recognition scheme depends on the successful solution of both of these problems.

In this work a solution to the above problems is attempted by analogue-digital technique. This technique profits from the advantages of both of the approaches. Pertinent information for identification is acquired by an analogue technique for two reasons: (i) information can be gathered almost instantaneously due to the parallel operation; (ii) the analogue method defers quantization of the input stimuli and thus allows greater use of all the information present.

The selection of the required information is a two stage process. In the first stage the letters and the numerals are divided into four basic sets: the figure eight, the zero, the I and the X. The second stage is a detailed examination of the individual characters. The characters are examined for the presence or absence of a set of eighteen characteristics. These characteristics have to be a sufficient set though not a unique one.

After all the information has been obtained by the analogue technique an on-line digital computer selects the correct response. The decision process used in the digital computer is based on the previous learning in which the computer derives the probabilities of occurence of the characteristics and the threshold values to determine the presence or absence of a characteristic. Once the above probability densities have been determined the computer is ready for the identification of the unknown characters.

CHAPTER II

OUTLINE OF THE METHOD

The set of elements that this recognition device will be dealing with is that consisting of the twenty-six letters of the alphabet and the ten arabic numerals. The characters are to be written in capital block letter form as opposed to lower case or italicized letters. Only two-dimensional black and white characters can be considered. Variations in size and personal style are permitted provided that they are not excessive. The individual characters are written with a very thick pen because of the coarse photo-grid used in the device.

The characters to be identified will be projected on a grid of photo-diodes. This grid will consist of an 8 x 10 array of diodes. The size of the grid bears little significance to the process and the chosen size is basically for convenience because of the vast amount of wiring involved. Eighty diodes is a sufficiently large number to obtain the required amount of data for identification and yet small enough to avoid the tedious problem of wiring.

During the simulation of several portions of this device it was noted that the majority of letters were higher than they were wide. Thus eight columns rather than ten were used so as to make an efficient use of all the diodes present in the array.

Since the analogue portions of the device utilize a correlation technique it is necessary to have letters of uniform size. This will be accomplished by projecting the letters onto the array of photo-diodes so that they fill as much of the available area as possible. One way to accomplish this is by means of a zoom lens which can expand or contract the letters uniformly in all directions. For example, when expanded uniformly the letter I will first strike the top or bottom of the matrix. The expansion would then be stopped and the letter centred in the vertical direction. When centred, expansion would begin again and the process would stop when the letter touched both the top and bottom of the array. Finally it would be centred in the horizontal direction. Alternately, the letter M would touch the sides of the array first and then be centred horizontally.

When the unknown letter, let us say the letter I, has been expanded uniformly, the diodes on which the letter falls would be generating voltages and those on which it did not fall would have no voltage. The edges of the letter may be rather "foggy" due to magnification and thus require sharpening. The sharpening of the letters will be done by a two-dimensional detail filter first built by Taylor[19]. This filter adds more significance to the edges and corners of the pattern than to the central portions which provide less information.

After the edges and corners have been sharpened the letters are classified into four sets by a classification unit. This unit compares the unknown to each of four standard patterns, derives a correlation coefficient for each set and places the unknown in the set with the largest correlation coefficient. For example, the letter I would be placed in the I set.

The unknown is then examined for the presence or absence of each element of a set of eighteen characteristics. Circuits for each characteristic give an output voltage derived from the overlapping of the unknown character and a standard pattern.

These eighteen voltages along with the information regarding the set to which the character belongs is transmitted to an on-line digital computer. The computer will be programmed to operate on the information supplied so that it can identify the unknown character. The details of this decision process are given in a later chapter.

CHAPTER III

ACQUISITION OF DATA

3.1 Normalization

The concept of normalization, that is having a common base for all signals, is an extremely important factor in this device. This is due, in part, to the analogue techniques employed in the device and in part to the thresholds used for the identification of unknown characters. The effect of such factors as change in light intensity due to line voltage variations, change in background intensity and difference in the reflectivity of the unknown may be minimized by normalization.

Essentially the normalization consists of controling the projector luminosity by a voltage generated in the system. Alternatively it can be achieved by dividing all signal voltage outputs by one of the voltages in the system.

The first alternative is easy to implement. A thyratron supplying the required voltage for the projector can be controlled by the reference potential. The question remains about the localization of the reference potential. Two obvious choices are that the control be such that (i) the sum of all output voltages of the array be constant, or (ii) that the sum of the outputs of the detail filter be a constant value.

Another choice would be to use the largest output voltage from the classification unit as a base and divide all other voltages by this number. However, this would give rise to numbers of very small magnitude. These numbers would lead to difficulty in the analogue to digital conversion.

For the present, the simple technique of keeping the sum of the detail filter outputs constant is chosen. This may have to be modified on later analysis.

3.2 Two Dimensional Detail Filter

The purpose of the two dimensional detail filter is twofold: to limit the amount of input noise and to aid in the extraction of information from the input pattern. To accomplish this, the two dimensional detail filter emphasizes the corners and edges of the pattern. This emphasis essentially consists of a reduction in the photodiode voltage. The reduction being the largest for the least important outputs and the least for the most important outputs. For the purpose of illustration each diode will be represented as a square. The part of the area covered by the pattern will be shown with diagonal lines across it (hatched) and the remainder will be blank (unhatched).

It is assumed that important information about a picture (pattern) is obtained from the corners and edges. Thus the voltage signals from the corners and edges of the pattern are considered as more important than those from the central portions of the pattern. The amount of information (detail) that each square of the input array contains may be estimated by the number of adjacent squares that contain signals from the pattern. For example, the amount of detail represented by a square at the corner of the pattern will be greater than one in the central portion because the central portion is surrounded by a greater number of squares with signal voltages. Thus by employing this negative weighting the contrast in the pattern can be enhanced.

The squares (photo-diodes) in this array may be designated by their location, i.e. by row (m) and column (n). The outputs of the diodes which are also inputs to the detail filter may be written as i(m,n) and o(p,q). Similarly the outputs of the detail filter may be written as O(m,n).

Each detail filter operates on one photo-diode output at a time and takes into account the state of the twenty transducers surrounding the central one as shown in the signal flow diagram of figure 1.

A detail filter similar to the above is associated with each square of the rectangular array of diodes. Only the twenty surrounding diodes are used as was the case in Taylor's device[19]. A large number would not provide any more detail but would add a great deal of wiring.

The equation relating the output of a detail filter

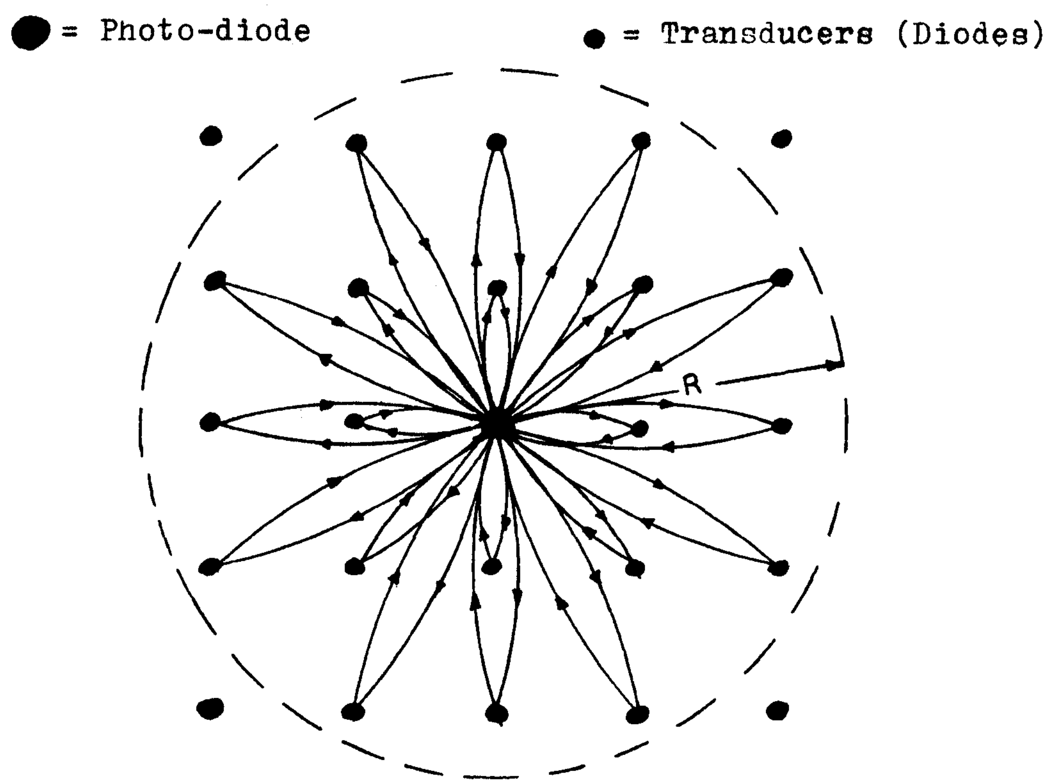


Fig. 1 Signal Flow Diagram of a Two-Dimensional Detail Filter

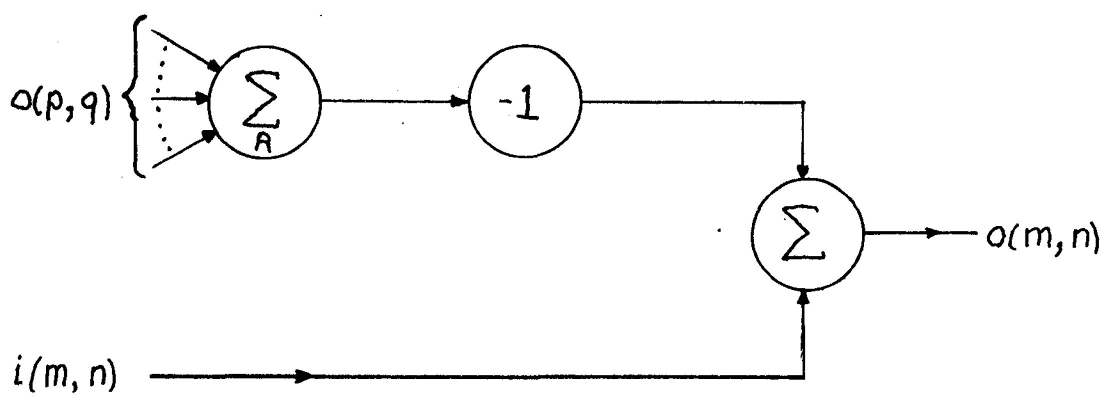


Fig. 2 Logic Diagram of a Two-Dimensional Detail Filter

to its input is defined below

$$O(m,n) = i(m,n) - k \underset{R}{\;} o(p,q)$$

where o(p,q) are the twenty inputs surrounding the input labelled i(m,n) and k is a constant dependent on the circuitry. The twenty inputs o(p,q) are those within a radius of $R = 2\frac{1}{2}$ units where a unit is the distance between the centers of adjacent squares.

The logic diagram of the detail filter is shown in figure 2 on the previous page.

A numerical example of the operation of the two dimensional detail filter is discussed in Appendix A.

CHAPTER IV

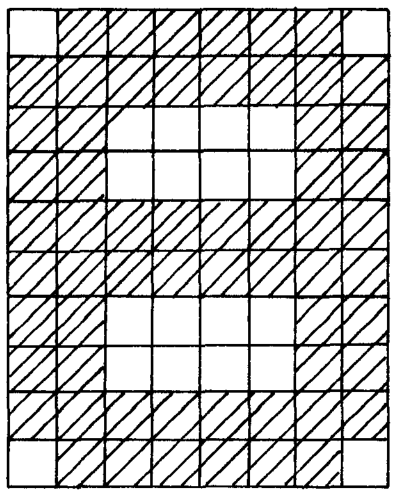
THE IDENTIFICATION PROCESS

4.1 Classification Units

The classification units divide the set of letters and numerals into four subsets. These subsets (shown in figure 3) are designated as the figure eight, the zero, the I and the X. This division makes the subsequent identification simpler because there are fewer characters to be analyzed in any subset.

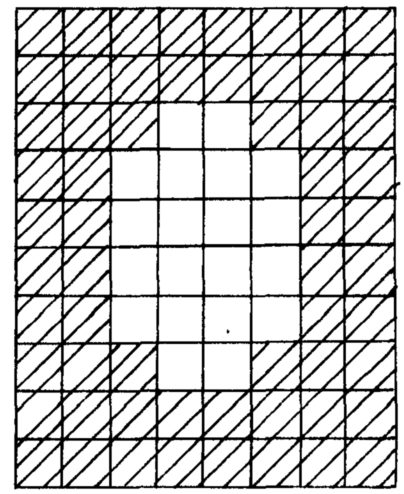
The logic employed in the implementation of the classification units is relatively simple. Signals from the two types of transducers are individually added and the sums are then subtracted to obtain the required coefficient for each set. The logic diagram for this unit is shown in figure 4.

The classification unit acts essentially as an addition unit. It adds together all those voltages that are generated by the diodes in the squares that correspond to the hatched squares of a classification unit shown in figure3. It also adds the voltages from the remaining squares of the array and changes the sign of this second sum. Finally both of these voltages are algebraically added to give the final result. All the addition units operate in parallel. Circuits used for the classification



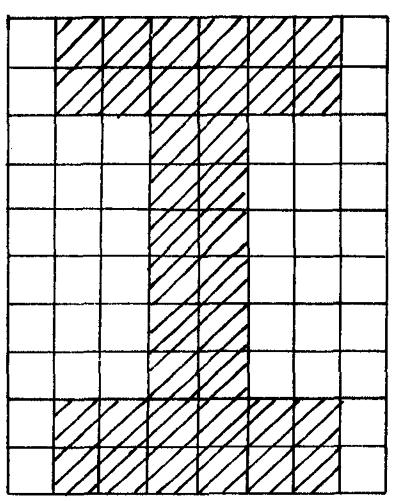
(i) Figure eight

First Set



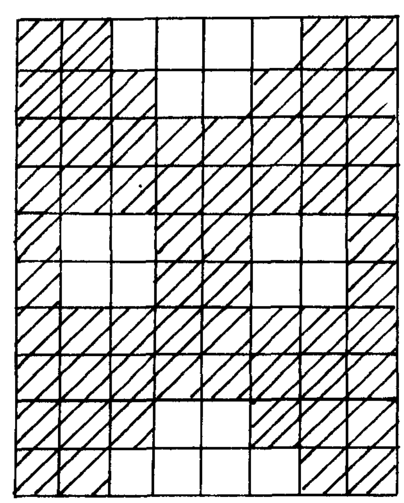
(ii) Zero

Second Set



(iii) I

Third Set



(iv) X

Fourth Set

Fig. 3 The Four Basic Subsets

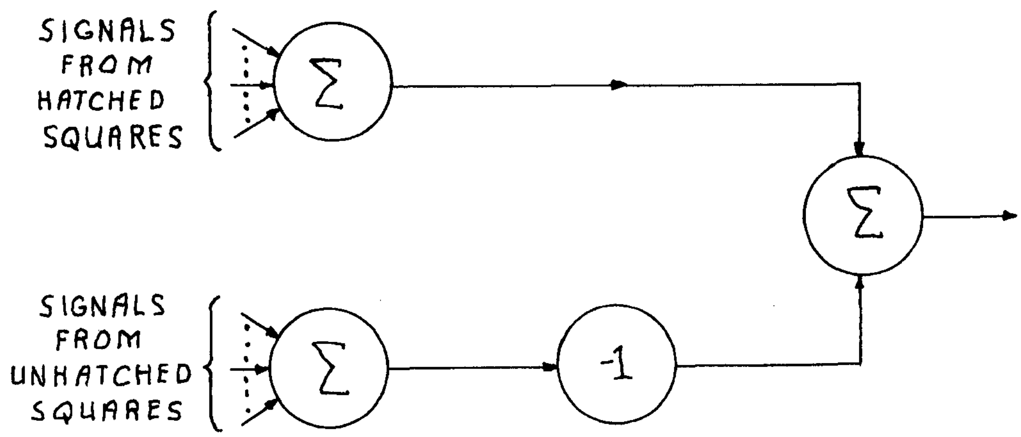


Fig. 4 Logic Diagram of a Classification Unit

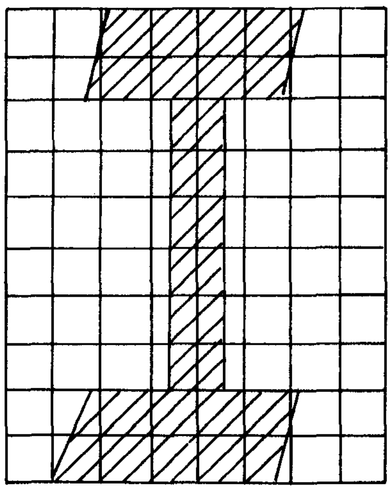


Fig. 5 Letter I of Example

units are discussed in appendix B.

The four resulting numbers may be considered as cross-correlations for the unknown character (the letter I in the example of figure 5). The unit with the highest output voltage indicates the subset with the highest cross-correlation. The unknown character is thus an element of the subset represented by this unit.

The selection of the unit with the highest output is accomplished by a circuit operating in an analogue fashion. It is proposed that the signals be subtracted from each other in all possible ways (in this case there would be twelve ways). This would yield four sets of three numbers. The set with three positive numbers would then be the desired set.

For the purposes of simulation, cardboard sheets with an array of two inch squares were used. Each of the four basic patterns were coloured on one of these sheets. Then the various letters were projected onto the sheets. First those portions of the letter that corresponded to the coloured squares of the matrix were counted. Then those portions of the letter that corresponded to the uncoloured squares were counted. Finally these two counts were subtracted (the second from the first) and the cross-correlation coefficients established. There was no weighting of the pattern, a departure from the proposed device. Also, all extraneous lines or dots were ignored and the totals counted were only to the nearest half square. The simulation employed here, although rather course, served to verify the choice of the four basic subsets. The sample handwritings used in this simulation are shown in Appendix D.

The table 1 was obtained when the letter I was projected onto each of the cardboard sheets. As can be seen from the table, the letter I falls into the third set. That is to say

$$I \in \{III\}$$

In a similar manner all the letters and numerals were classified into the four subsets. The results from seventeen sheets of thirty five characters are given in Table 2. Due to the large variations in individual printing several of the letters fall into two subsets. This fact does not confuse the division as in the final division the letter can be placed in both sets. The division of the characters into subsets is given in Table 2. This may also be summarized as follows:

FIG. EIGHT = ⊟ = (A,B,E,F,G,H,P,R,S,U,Z,2,3,5,6,8,9)

ZERO = □ = (C,D,G,J,L,O,Q,U)

I = (I,T,1,7)

X = (A,H,K,M,N,R,V,W,X,Y,Z,4)

$$⊟ \cap □ = (G,U)$$

$$⊟ \cap I = \emptyset$$

$$⊟ \cap X = (A,H,R,Z)$$

$$□ \cap I = \emptyset$$

$$□ \cap X = \emptyset$$

$$I \cap X = \emptyset$$

Table 1 : Selection of the Set for the Letter I

Set	I	II	III	IV
Hatched Squares	18	16	22	12
Unhatched Squares	4	6	0	10
Difference	14	10	22	2

Table 2 : Frequency of Letters in Sets

Letter \ Set	I	II	III	IV
A	8	0	0	11
B	15	0	0	1
C	1	15	0	1
D	3	15	0	0
E	14	0	1	1
F	15	1	0	2
G	11	9	0	1
H	14	0	0	7
I	0	0	15	1
J	6	9	5	2
K	1	0	0	15
L	3	14	2	1
M	3	1	0	14
N	2	0	0	15
O	3	16	0	1
P	14	0	0	2
Q	3	15	0	0
R	10	0	0	8
S	15	1	2	1
T	2	1	15	2
U	8	12	0	4
V	6	0	0	15
W	2	0	0	16
X	0	0	0	16
Y	3	0	4	14
Z	9	3	4	8
1	0	0	14	2
2	13	3	3	4
3	15	2	1	0
4	6	1	0	11
5	10	2	4	2
6	10	1	4	3
7	5	2	9	4
8	16	0	2	1
9	12	1	2	4

The information about the one or two possible subsets that contain the unknown is transmitted to an on-line computer. The computer can then refer to the section of its memory that contains data about this subset,

4.2 Characteristic Units

The second stage of the identification process may be considered as the structural examination of the unknown character. This circuit is designed so as to completely identify the letters in each set. The technique employed here will in part be a cross-correlation technique.

In the classification unit, a cross-correlation between the unknown and four standard patterns was obtained. In this unit only parts of the unknown are matched against standard parts or characteristics. Eighteen such parts have been chosen. These eighteen characteristics are shown in figures 6 and 7.

The logic unit employed to obtain the match or the cross-correlation against each of the eighteen characteristics is shown in figure 8. These like all other units employed in the recognition device are very simple to construct. The signals from the hatched portion of the grid are added together and converted to a binary number suitable for use in the on-line computer. Each of the eighteen characteristics is treated in the above manner so that there are eighteen "bits" of information for use

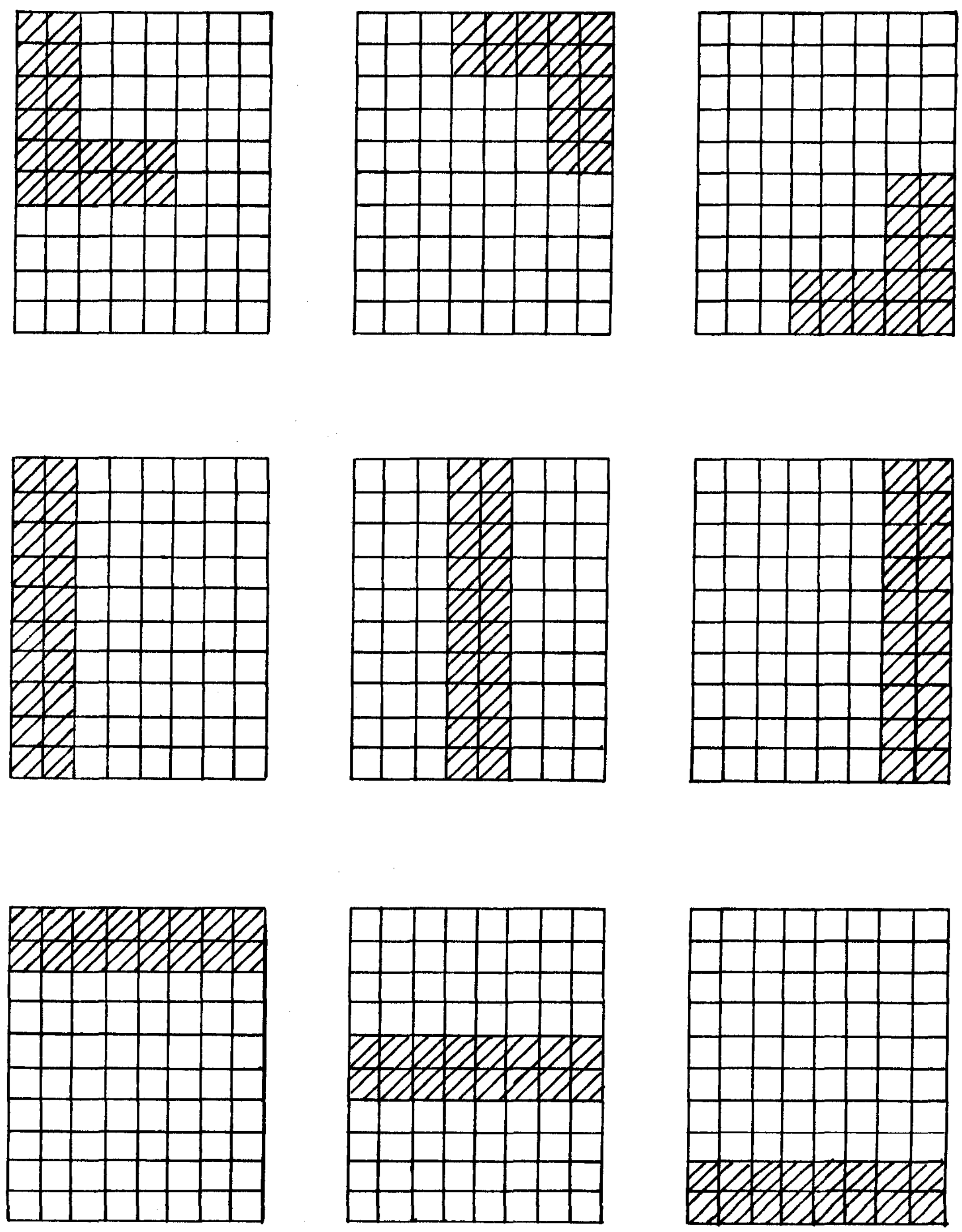


Fig. 6 The Characteristics for Identification

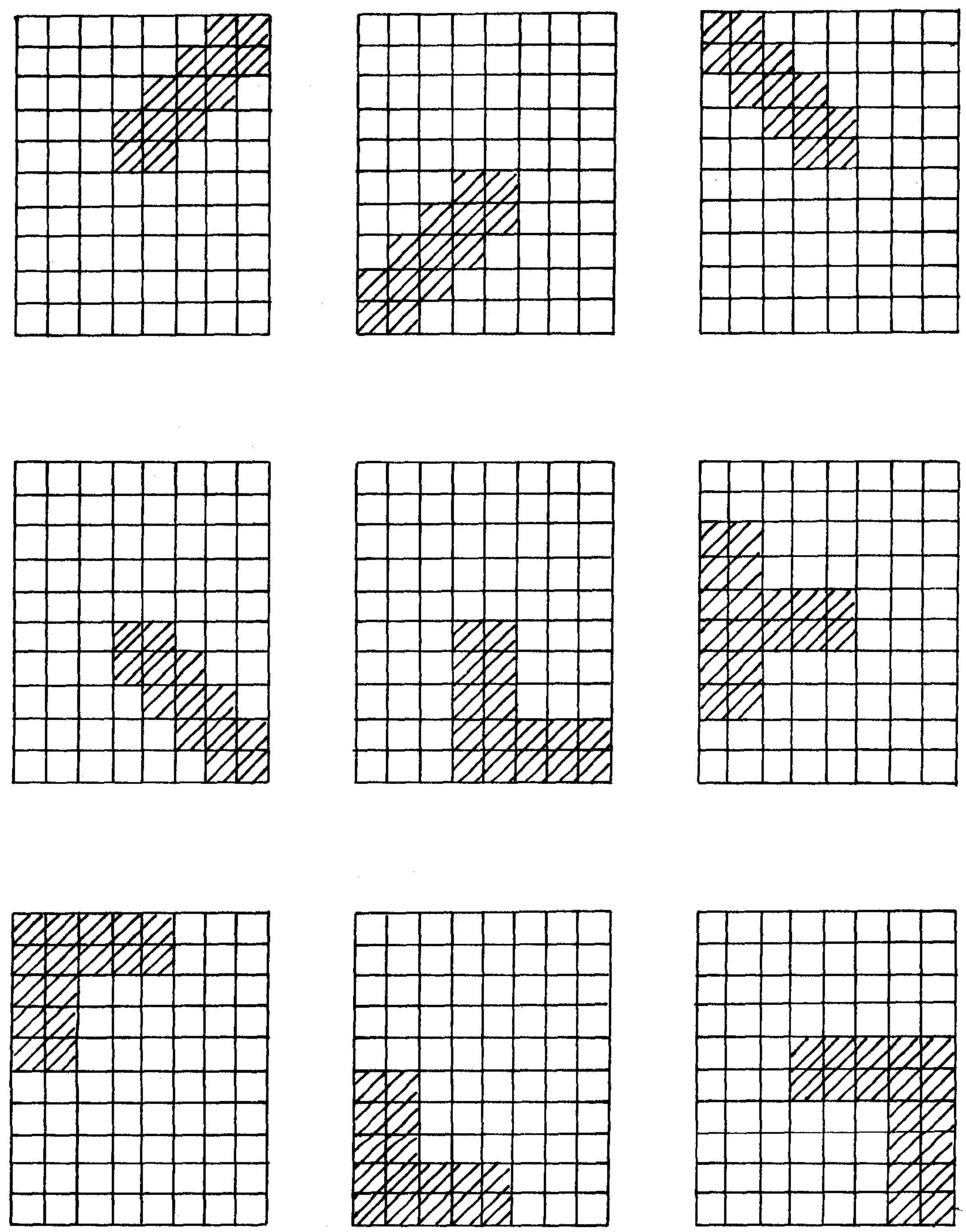


Fig. 7 The Characteristics for Identification

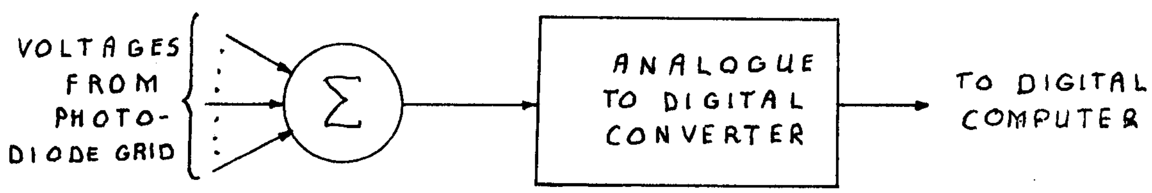


Fig. 8 Circuit for Characteristics

in the final identification process. The circuit used for the above unit is given in Appendix C.

The above process was simulated in a manner similar to the one used for the classification units. That is, each characteristic was drawn on a grid and those squares corresponding to the squares of the individual characteristics were counted and recorded. In this manner, the information required for the final identification stage was obtained. Due to the wide variation in individual handwriting it was found that a large number of samples was needed to obtain sufficient information for identification.

Because of the tedious nature of the work and the large number of samples needed this final stage of the process was not completely simulated. Five complete sets of data were obtained and from these it was concluded that due to the contradictions in identification a large number of samples was needed. Then statistics concerning the letters and their characteristics could be obtained to aid in the final identification.

The manner in which the characteristics are chosen will be described in the next chapter as this process will be done by the digital computer.

CHAPTER V

THE DECISION PROCESS

The final identification is carried out by an on-line digital computer using the information gathered in the previous analogue stages of the device. This may be considered in two parts. The first of these is the learning process in which the computer will derive statistics to be used in the identification of the unknown characters. For convenience of discussion each of the two computer programmes will be divided into several subsections.

5.1 The Learning Section:

The information to be processed can be represented by three dimensional arrays. However, for the purpose of simplicity of explanation and computer storage two dimensional arrays are used. Some of the symbols and arrays employed in the learning process are shown on the following two pages.

The first step in the learning process is to establish the thresholds. These are voltages that determine whether a characteristic is present or not. That is, if the voltage output of a particular characteristic unit is equal to or above this threshold value, the characteristic of interest is assumed to be present and is absent otherwise.

TABLE 3: Symbols Used in the Flow Diagram

J = Letter set

K = Letter characteristic set

M = Letter

THR = Threshold array

IND = Identification array of coded letters

ADDT = Cumulative sum of threshold voltages

CNT = Counter to count presence of characteristics

PROB = Array of probabilities of occurence of characteristics

CO.1(J) = Number of letters read in each letter set

CO.2(J,M) = Number of occurences of letter "M" in letter set "J"

WA--- = Area designated for storage of ---

LET(M) = list of alphanumeric symbols

DIFF(M) = Number of mismatches between the unknown character and those in the array IND (J,K,M)

INSIG = an array giving the "closeness" of fit of the mismatches in the unknown

OCC = Probability of occurence of letters in English text

ABS( ) = Absolute value

DUMMY = Temporary storage area

DUM = Temporary storage area

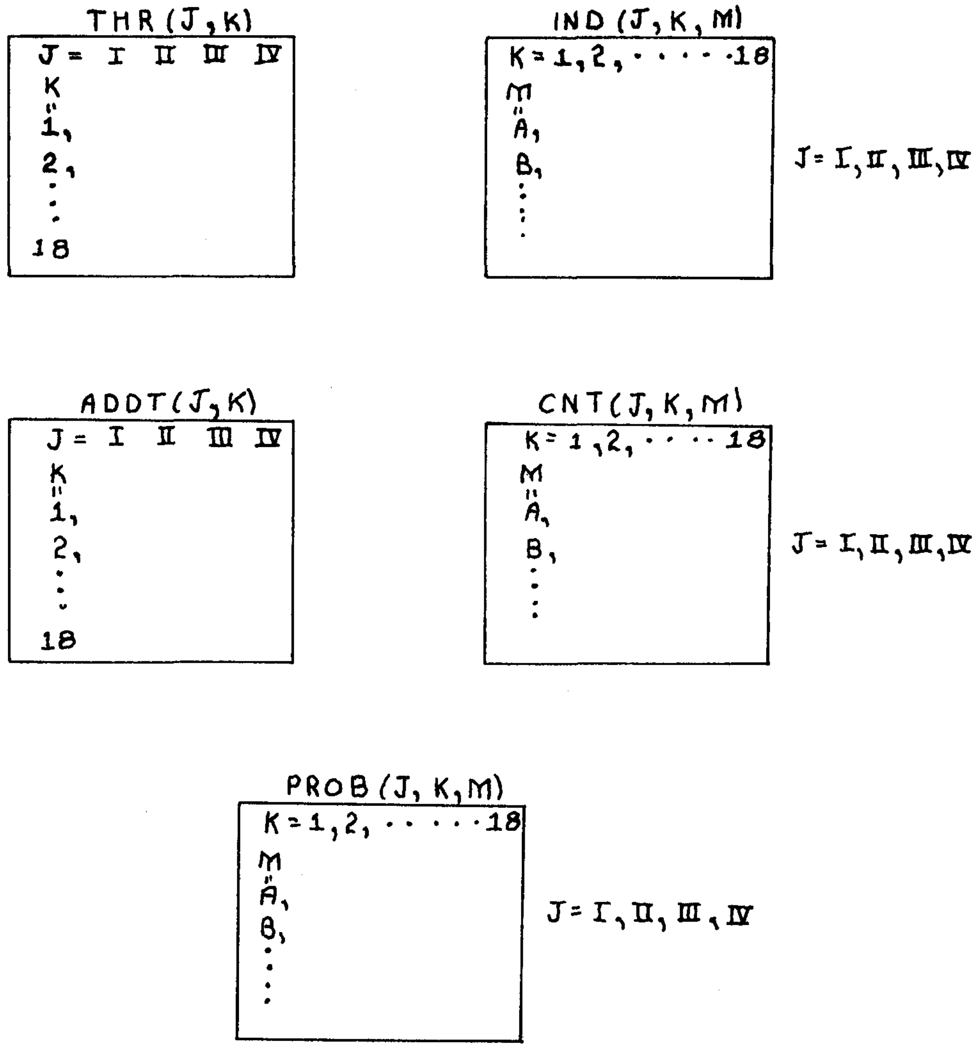


Fig. 9 Arrays Used in Learning Phase of Computer Program

The threshold value is obtained by evaluating all the voltages for a particular characteristic unit in each letter set. When this has been accomplished the identification array IND (J,K,M) which gives the codes of zeroes and ones for each letter is established by comparing the unknown to the threshold voltages. Finally the probability of occurence of a characteristic is established by counting the number of times a letter occurs and the number of times each characteristic of that letter occurs. The ratio of these two numbers establishes the required probability table, Prob (J,K,M). Also the array IND (J,K,M) is altered in that if a particular characteristic has a probability of fifty per cent or greater, a 1 is placed in the matrix, otherwise, a 0.

The various sections of the programme are shown in figures 14 to 19. In the first figure information regarding the set to which the character belongs is read into the computer. The first matrix to be filled is the threshold matrix, THR (J,K). Thus, the programme first checks to see if there is any information in the THR (J,K) array. If there is not, it places the eighteen characteristic voltages into this section. Also, these thresholds are placed in the ADDT (J,K) array and the counter CO.1 (J) is set to one. These two pieces of information will be used to determine the thresholds for a set. However, if information has previously been read in, it asks for the letter that is being read. Then it tests to see if the letter has been

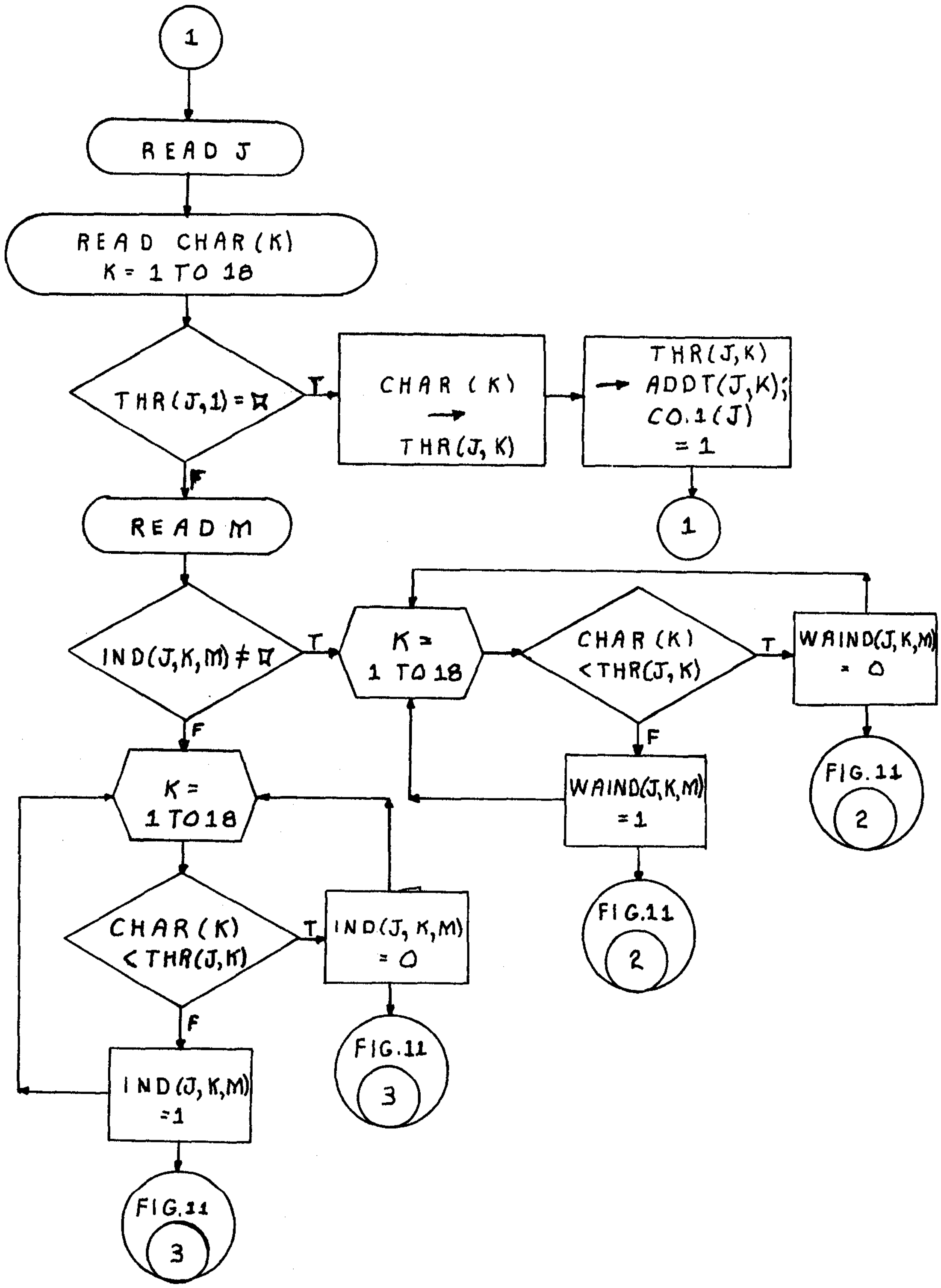


Fig. 10 Section One of Learning Phase

read before. In the event that it has been read before, the individual characteristic voltages are tested to see if they are above or below the threshold. A 1 is assigned to those above threshold and a 0 to those below threshold. The coded set of characteristics is placed into a work area, WAIND(J,K,M). If the letter has not been read previously, the characteristics are coded into a series of zeros and ones and placed directly in the array IND(J,K,M).

Section two of the learning phase determines the thresholds and establishes the probability of occurence of the characteristics. In the flow diagram branch 3 is followed only the first time that a new character is presented and branch 2 at all other times. First the counter counting the number of new occurences in a set is increased by unity. Then the accumulated sum in the ADDT(J,K) array is updated. The new thresholds are determined by dividing the ADDT(J,K) array by the number in the counter CO.1.(J) and then transferred to THR(J,K). If this is the first appearance of a character, the counter CO.2(J,M) which counts the number of occurences of an individual letter is set to one. Otherwise it is increased by one. Also the coded signal is placed in the counter CNT(J,K,M) which counts the number of times a letter occurs, the probability of occurence of a characteristic is calculated and placed in the array PROB(J,K,M).

Section three of the learning phase
is not an essential portion of the learning section and

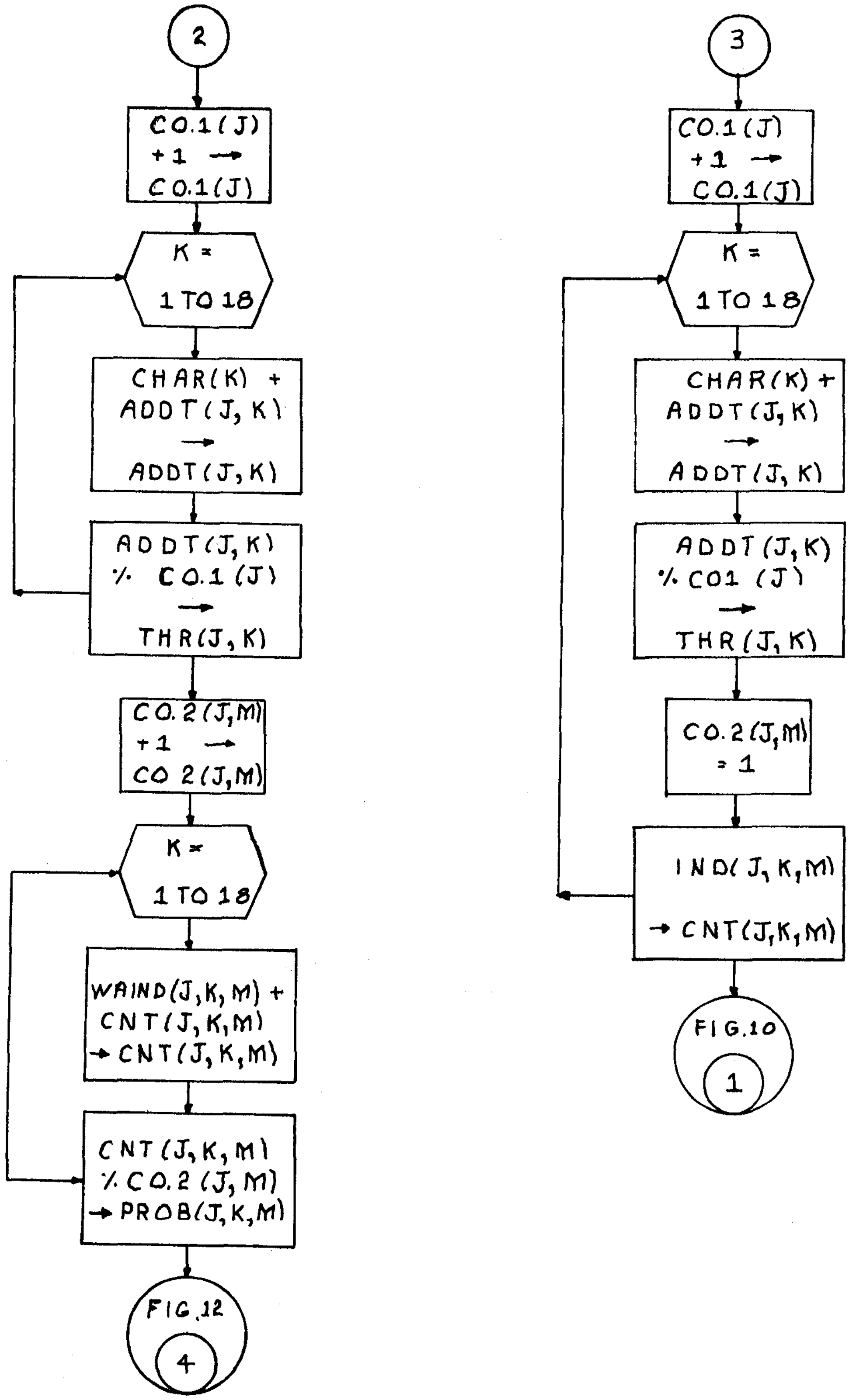


Fig. 11 Section Two of Learning Phase

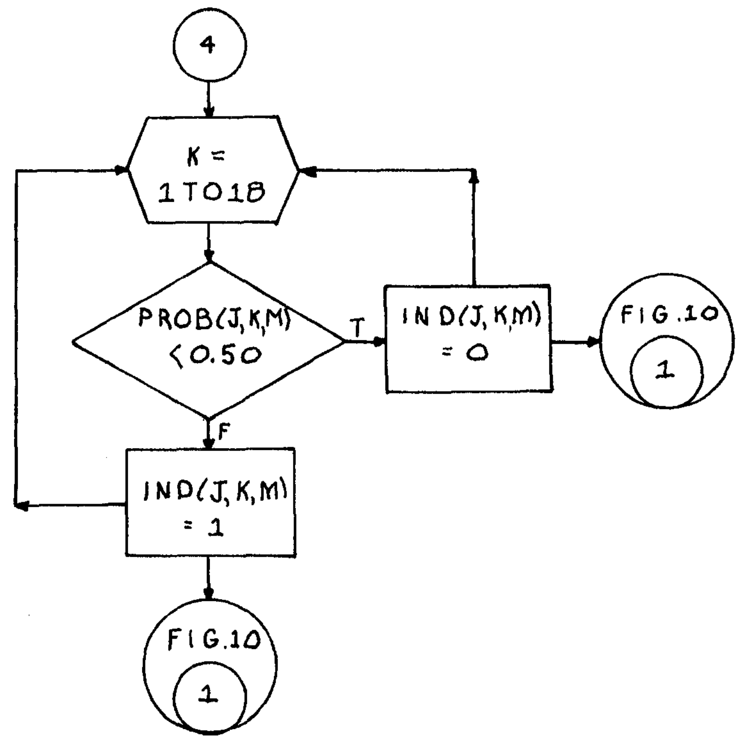


Fig. 12 Section Three of Learning Phase

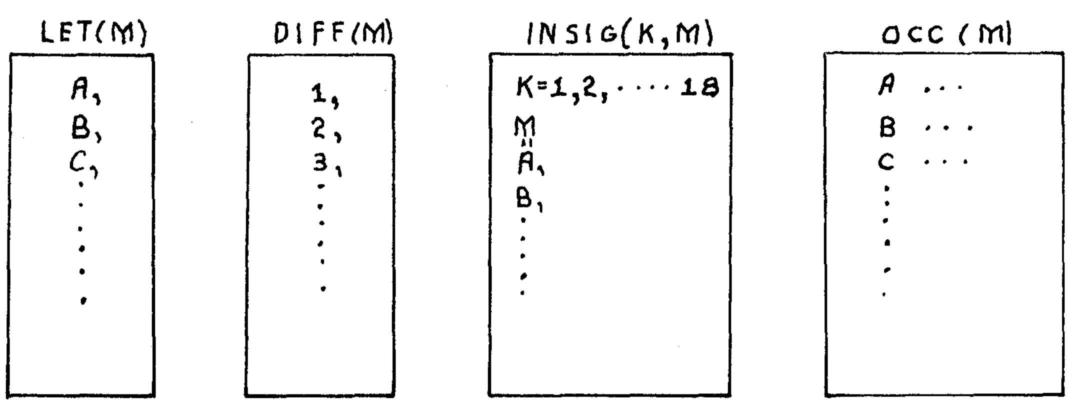


Fig. 13 Arrays Used in the Testing Phase of Computer Program

may be deffered to the beginning of the next section. This portion simply revises the array IND(J,K,M). It places a 1 in the array if the probability of occurence of a letter is greater than fifty per cent and a zero otherwise.

5.2 Identification of an Unknown Character

The final decision about the identity of the unknown will be based on three criteria. The first of these will be dependent on the match that the coded signal bears to the established codes in the array IND(J,K,M). That is, if the unknown matches one of these coded letters perfectly it will be chosen as the result. However, if there is no perfect match, the characters with the smallest number of non-matching characteristics will be processed. Use of the probabilities of occurence of the characteristics is made to calculate the most probable identification. Finally, if a decision cannot be made on this basis the character from this set with the highest probability of occurence is chosen.

The first section of this computer programme establishes the coded signal for the unknown character. Each characteristic is compared to the threshold level and coded as 0 or 1 depending on whether it is below or above the threshold value. Then the modulo two sum of this coded character and the established coded characters is formed. This sum determines which of the characteristics detected in the unknown are different from the established codes.

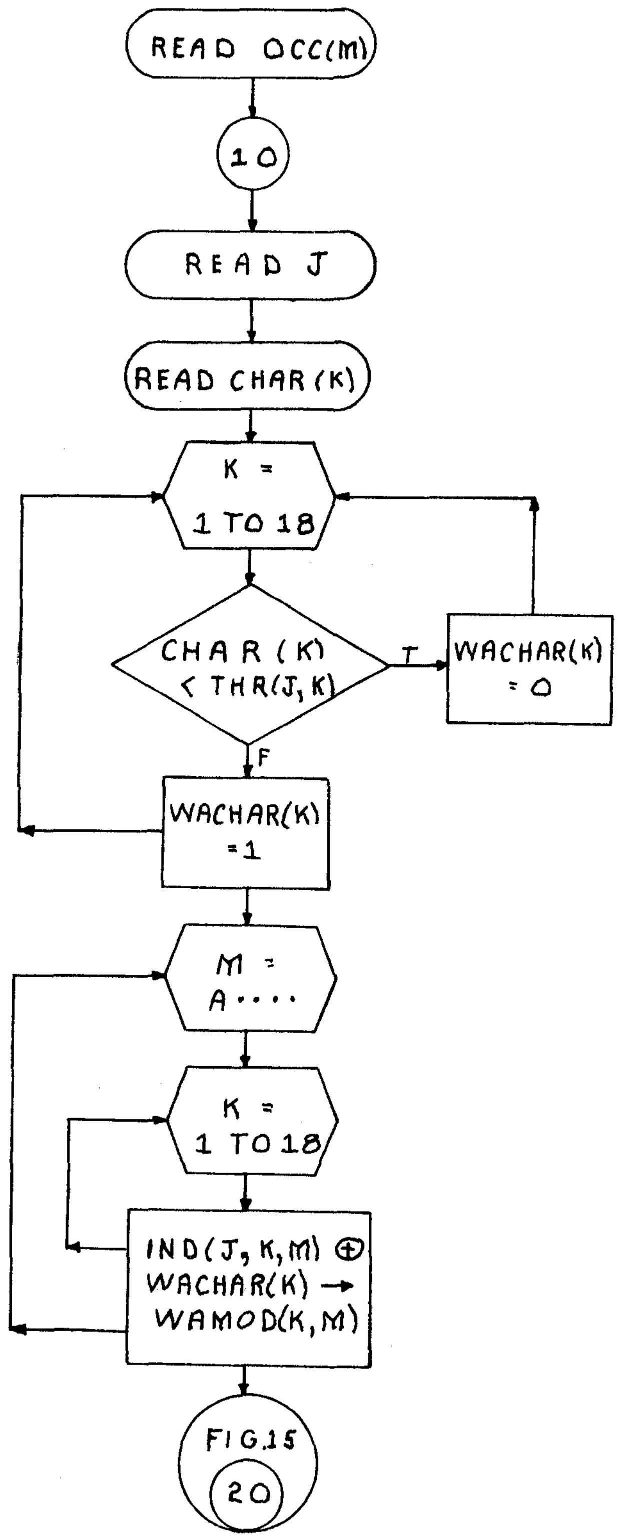


Fig. 14 Section One of Testing Phase

In the second section, the number of differences between the unknown and each of the characters in the letter set is determined and listed in DIFF(M). This list of differences is then arranged in decreasing order. The first letter of the list is then examined to determine if it matches one of the coded signals. If it does, the second letter in the list is also tested and if only one letter matches exactly this letter is chosen as the result. However, if none or two match, the second identification criterion must be employed.

Section three of the testing phase establishes the information to perform the the required test. First it determines those letters that differ from the established codes by three characteristics or less. The programme then operates on these letters and forms what is called here an "insignificance index" INSIG(J,K,M). This is simply an array giving the "closeness" of fit of each of the mismatches in the character. The "closeness" is based on the difference from fifty per cent of the probability of occurence of the characteristic. For example, if the third characteristic is different from the unknown and has a probability of occurence of sixty-two per cent, the "closeness" or insignificance index would be twelve. In this manner, those characteristics which are close to being the same as the unknown can be determined and this fact will be used in the second identification criterion.

In section four of the testing phase the computer

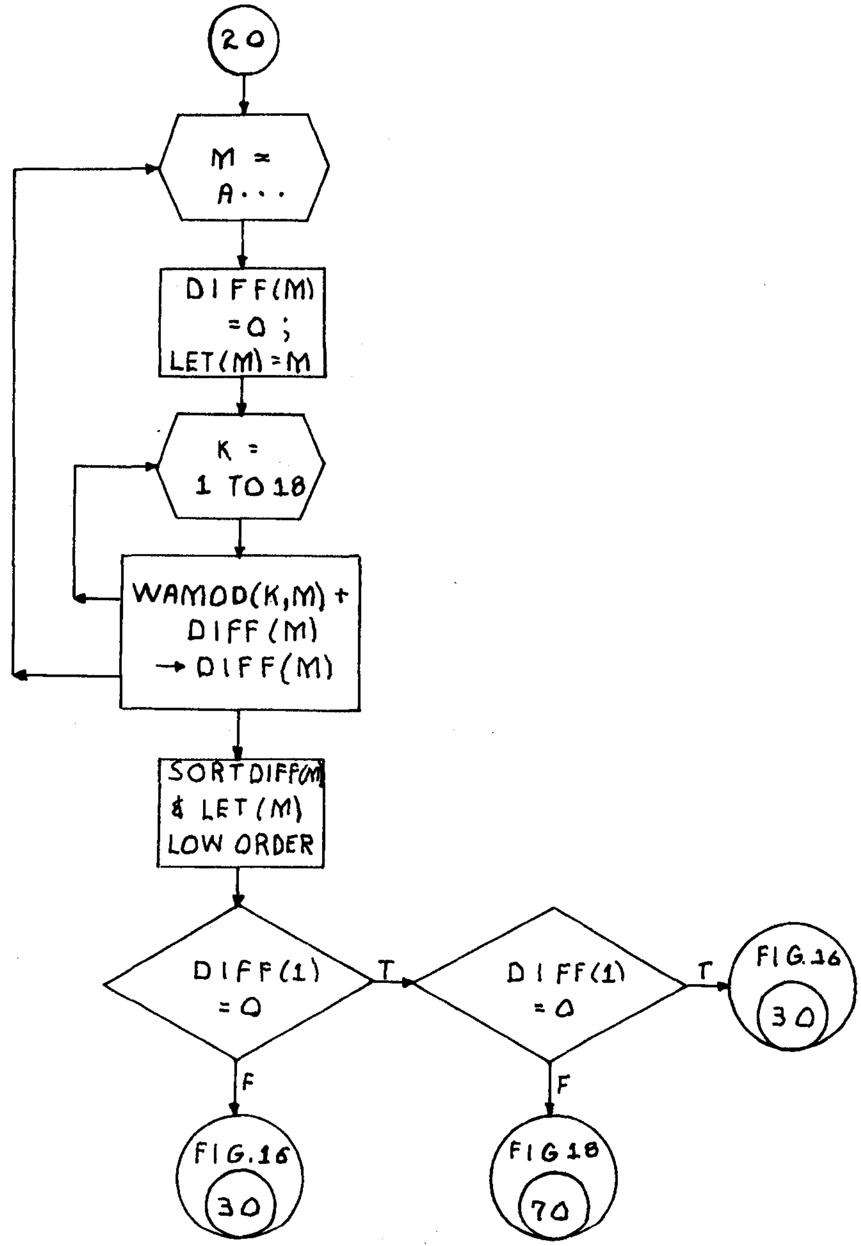


Fig. 15 Section Two of Testing Phase

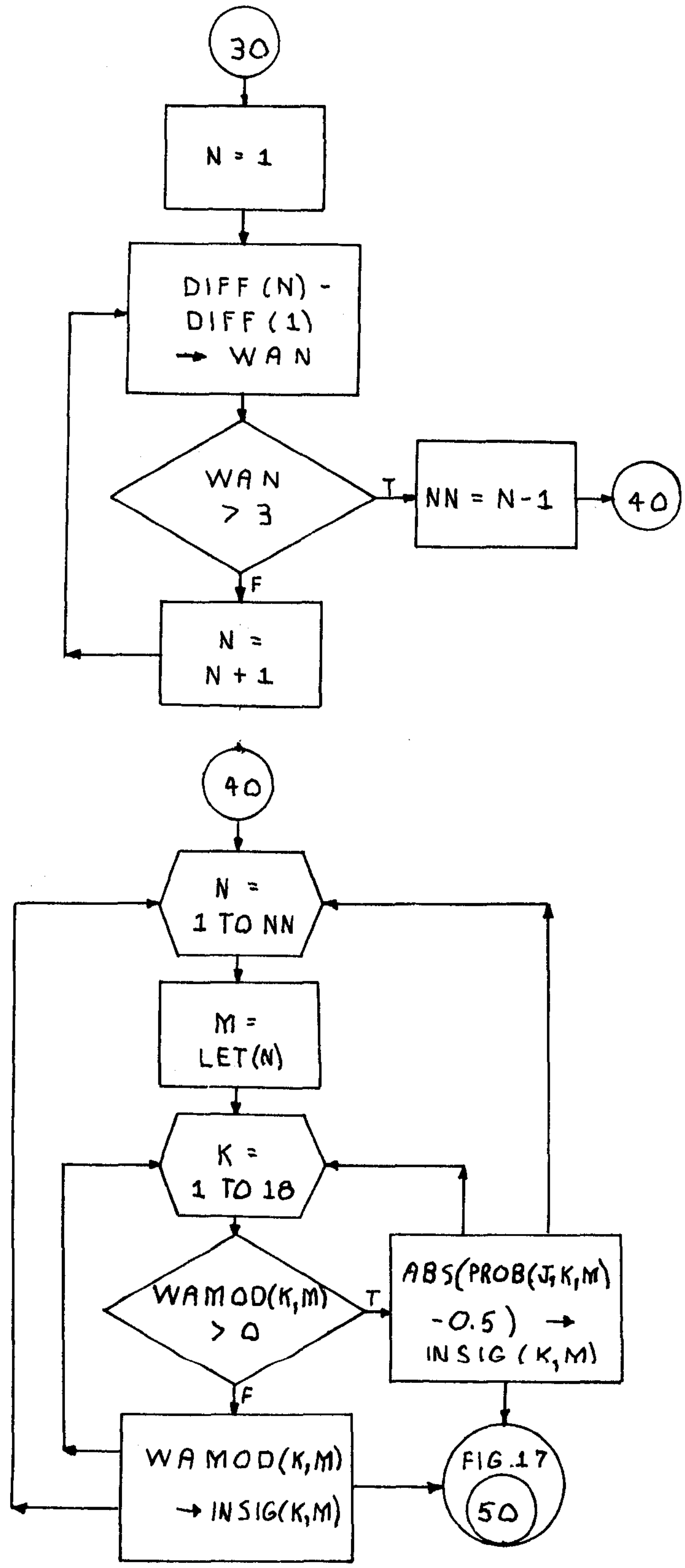


Fig. 16 Section Three of Testing Phase

programme examines the "insignificance index" array. First it adds together all the indices for each letter and places them in a work area WAINSIG(M). Then it determines the average value for each letter and sorts these values in decreasing order. Finally it tests to determine if the first two average errors are different. If they are, it chooses the first character in the list as the desired result. If the smallest average errors are the same the computer chooses the letter with the largest probability of occurence as the desired result.

Prior to printing the final result the programme tests a sense switch which can be set so that further learning may take place. If further learning is desired the programme transfers to section six of the testing phase and adjusts the probabilities of occurence of the characteristics as it did in section two of the learning phase. In the event that further learning is not desired the computer prints out the final result directly.

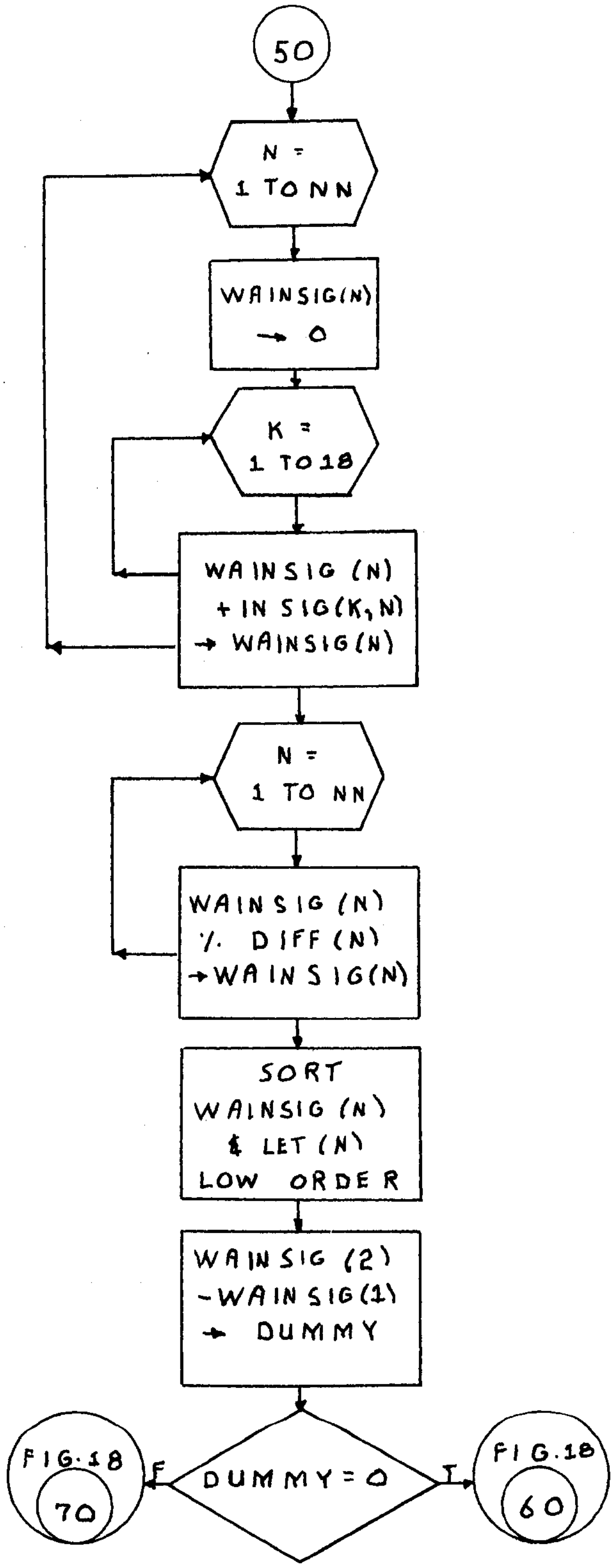
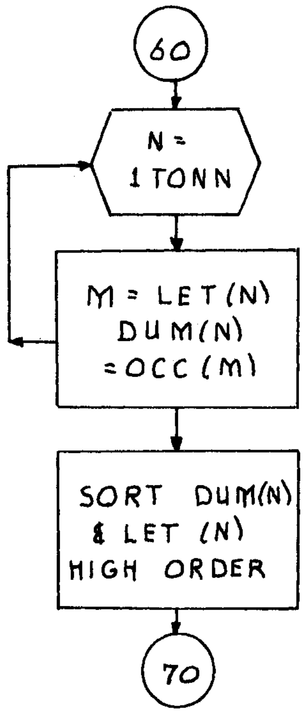


Fig. 17 Section Four of Testing Phase



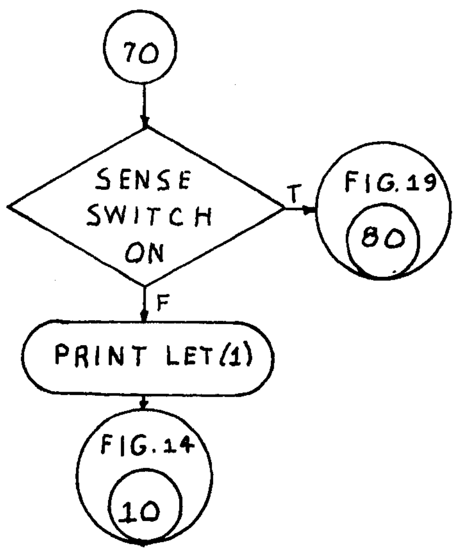


Fig. 18 Section Five of Testing Phase

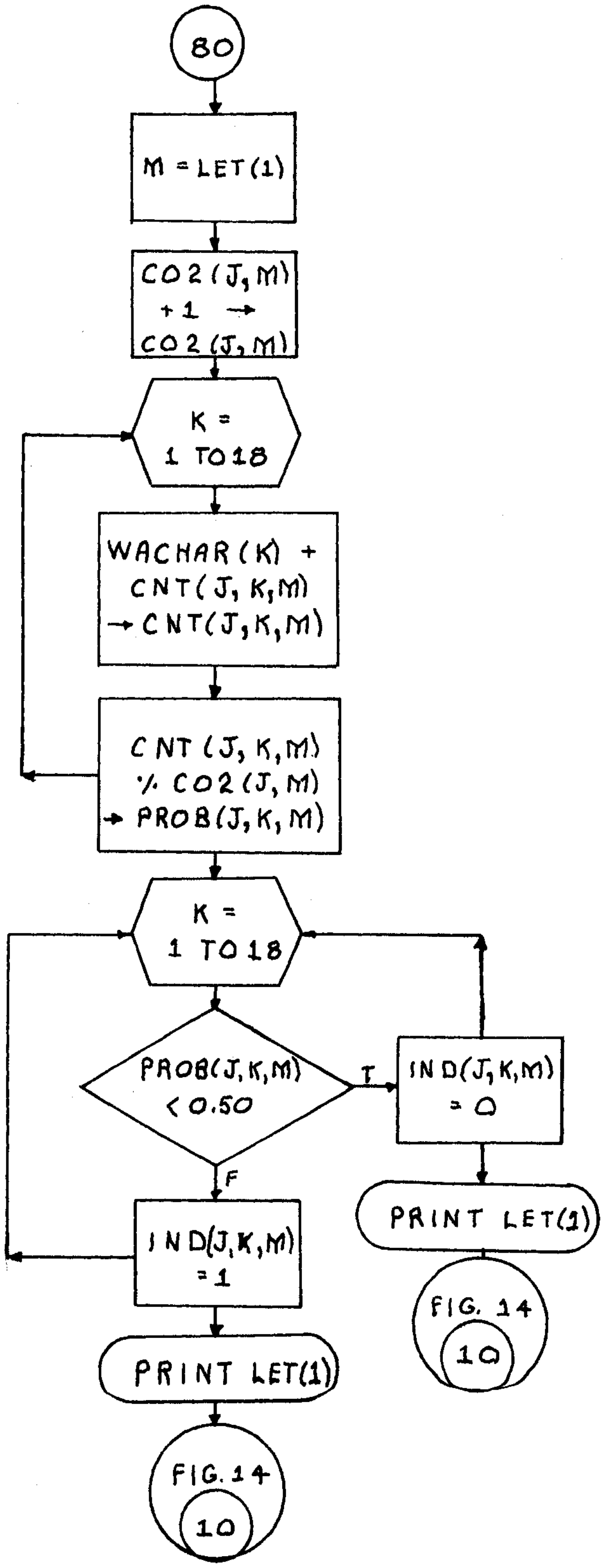


Fig. 19 Section Six of Testing Phase

CHAPTER VI

DISCUSSION

The majority of work done on character recognition devices has been with digital computers and very little work has been done using analogue computers. The present work describes an analogue-digital device employing the advantages of both of these techniques. The analogue portion provides speed and simplicity in the acquisition of data and avoids the problem of the quantization of the input information at too early a stage. A large memory storage with easy access is provided by the digital computer. While the complexity of the system has been reduced, the overall speed of identification has been increased. The division between the analogue and digital techniques occurs at the point where use of memory is called for in the decision process.

The proposal is outlined in more or less, block diagram form and some of the principles have been tested by easy simulation. Detailed testing of the concepts will now be undertaken by making phototypes of the different units. Some modifications of the proposal may then be found necessary.

No attempt has been made to mathematically prove the sufficiency of the proposed scheme. Further work in this direction will be very useful.

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APPENDIX A.

TWO-DIMENSIONAL DETAIL FILTER

The basic unit used in this stage is what Taylor[19] called an A-unit. this unit is basically an adder unit but the various inputs may be differently weighted, if it is so desired. Taylor has specified the design criteria for this circuit. The equation relating the output to the input of the two-dimensional detail filter is:

$$O(m,n) = i(m,n) - k\sum o(p,q) \quad \text{(A1)}$$

where o(m,n) is the output, i(m,n) is the input, o(p,q) are the twenty diodes surrounding i(m,n), and k is a gain constant dependent on the value of the resistors in the circuit.

The actual circuit is as shown in figure A1. If R = 20k ohms and the value of R_N is 500 ohms then

$$k = \frac{R_N}{R + R_N} = \frac{1}{41} \quad \text{(A2)}$$

For example, consider a 5 x 5 portion of the array as shown in figure A2. Assume that the output of each of the units in this array is 1 volt. The voltage appearing at the output of the two-dimensional detail filter connected to each of the elements of the array can be calculated using equation (A1). These outputs are shown in figure A3. The increase in contrast can be seen from this figure.

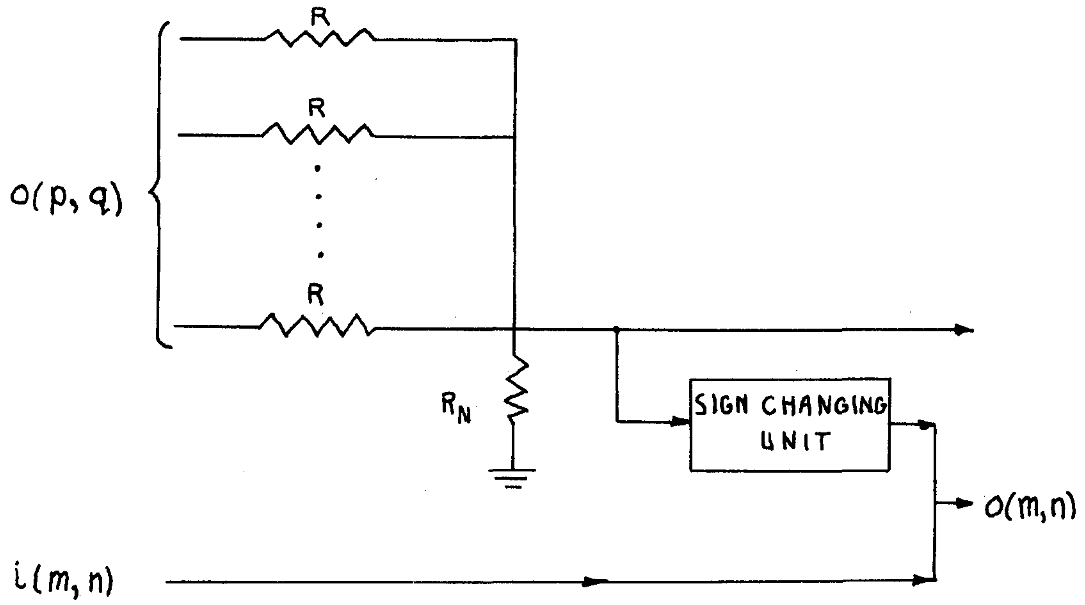


Fig. A1 Circuit Diagram of a Two-Dimensional Detail Filter

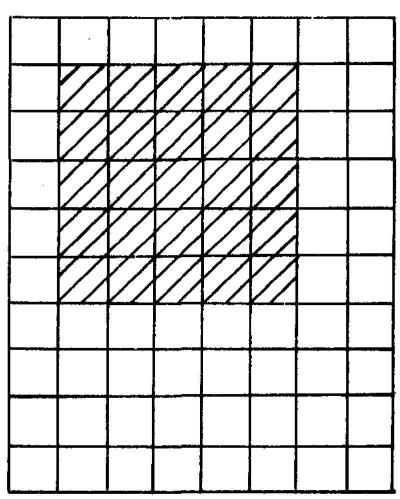


Fig. A2 A 5 x 5 Array of 1 Volt Signals

	.83	.76	.71	.76	.83		
	.76	.66	.59	.66	.76		
	.71	.59	.51	.59	.71		
	.76	.66	.59	.66	.76		
	.83	.76	.71	.76	.83		

Fig. A3 The 5 x 5 Array After the Detail Filter

APPENDIX B

CLASSIFICATION UNIT

The classification unit is somewhat similar to the detail filter (Appendix A) except that it consists of two summing units. The output of this unit is given by the equation:

$$v_o = \frac{1}{N + 1} \sum_{r=1}^{N} v_r \qquad \text{(B1)}$$

where v_o is the output voltage, v_r is the voltage at the input of the classification unit, and N is the number of inputs. The circuit of figure B1 can implement equation (B1).

In figure B1 the inputs v_R represent the voltage signal from the hatched squares and inputs v_U from the unhatched squares of the basic pattern, and v_o is the output. The output v_o is compared with the outputs of the three other classification units. The unit giving the highest output thus places the unknown character in the right subset.

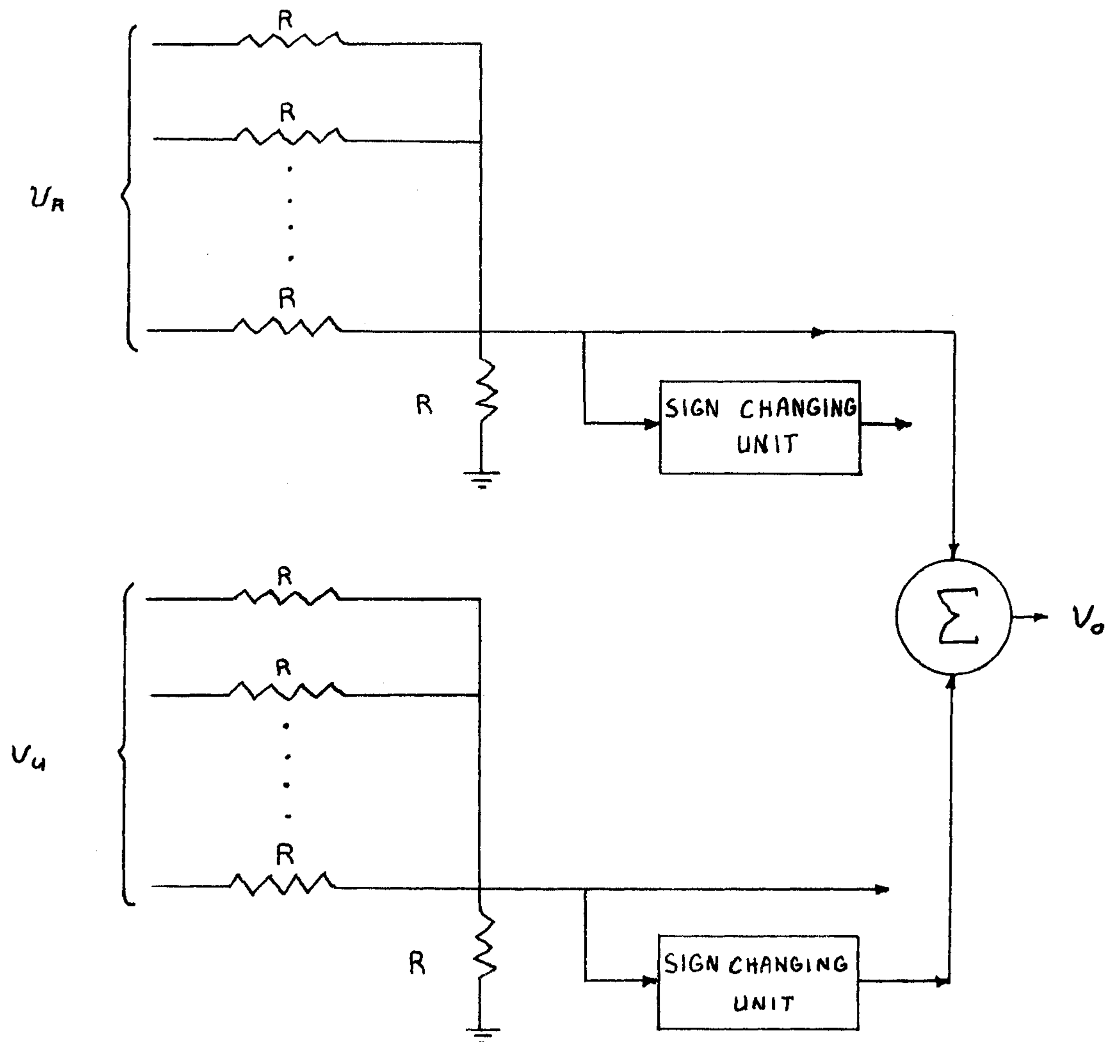


Fig. B1 The Circuit Diagram for a Classification Unit

APPENDIX C

CHARACTERISTIC UNIT

The characteristic unit is almost identical to the classification unit (Appendix B) except that there is only one set of inputs. This set consists of the terminals of the array corresponding to the characteristic of interest. The circuit performing this operation is shown below in figure C1.

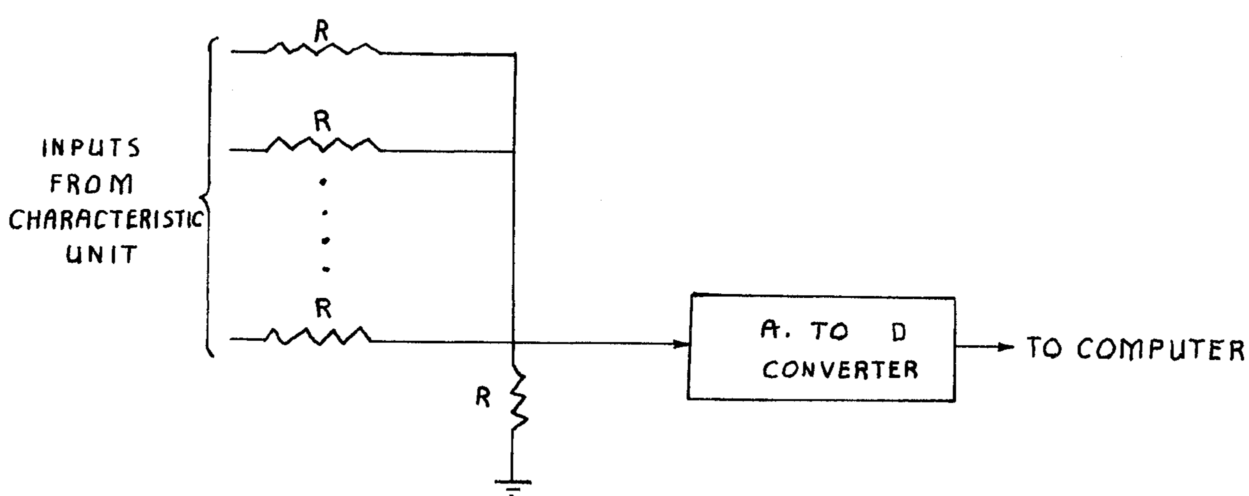
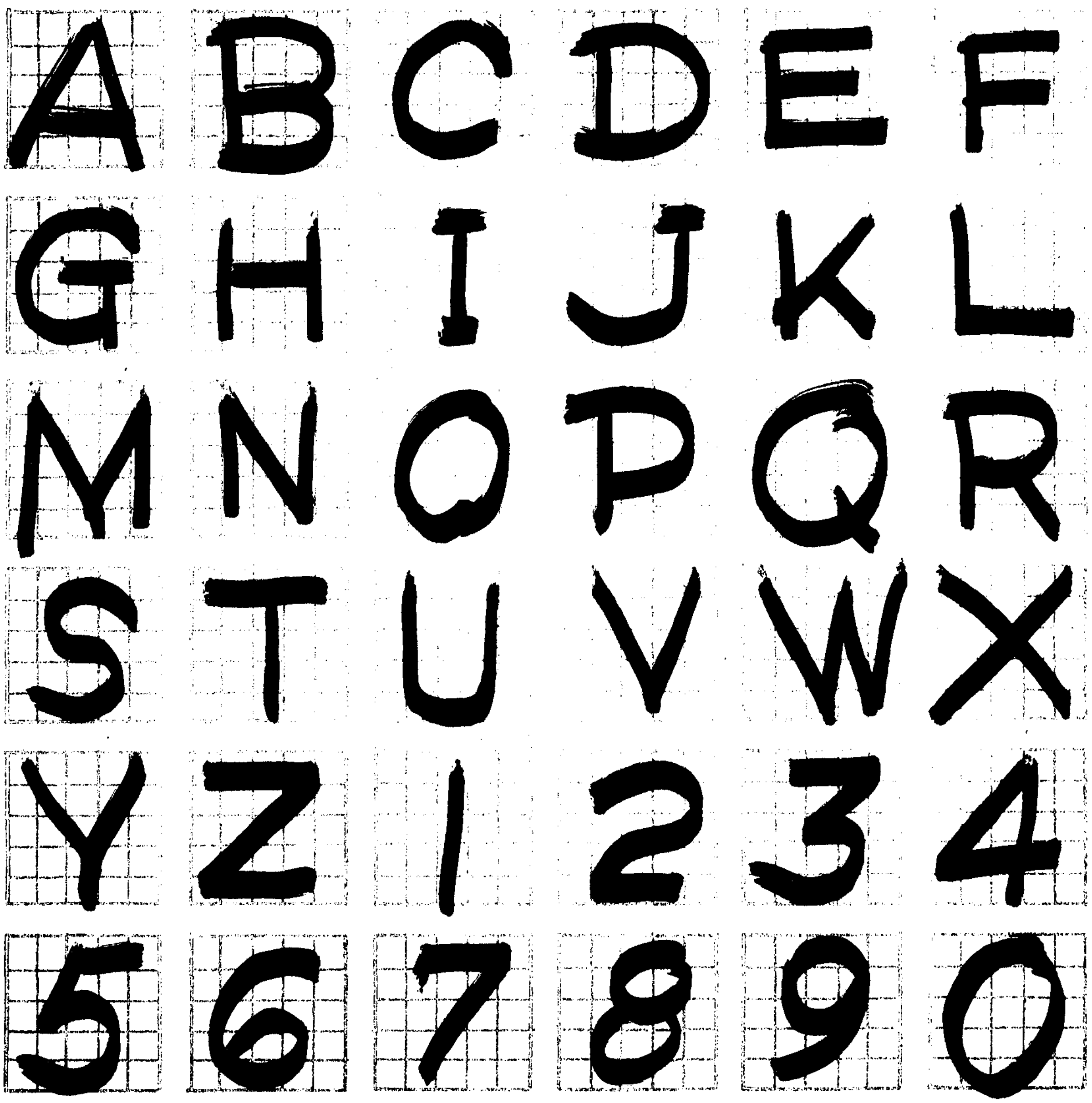


Fig. C1 The Circuit Diagram for a Characteristic Unit

APPENDIX D

Sample Handwritten Characters Used in the Simulation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Y Z 1 2 3 4
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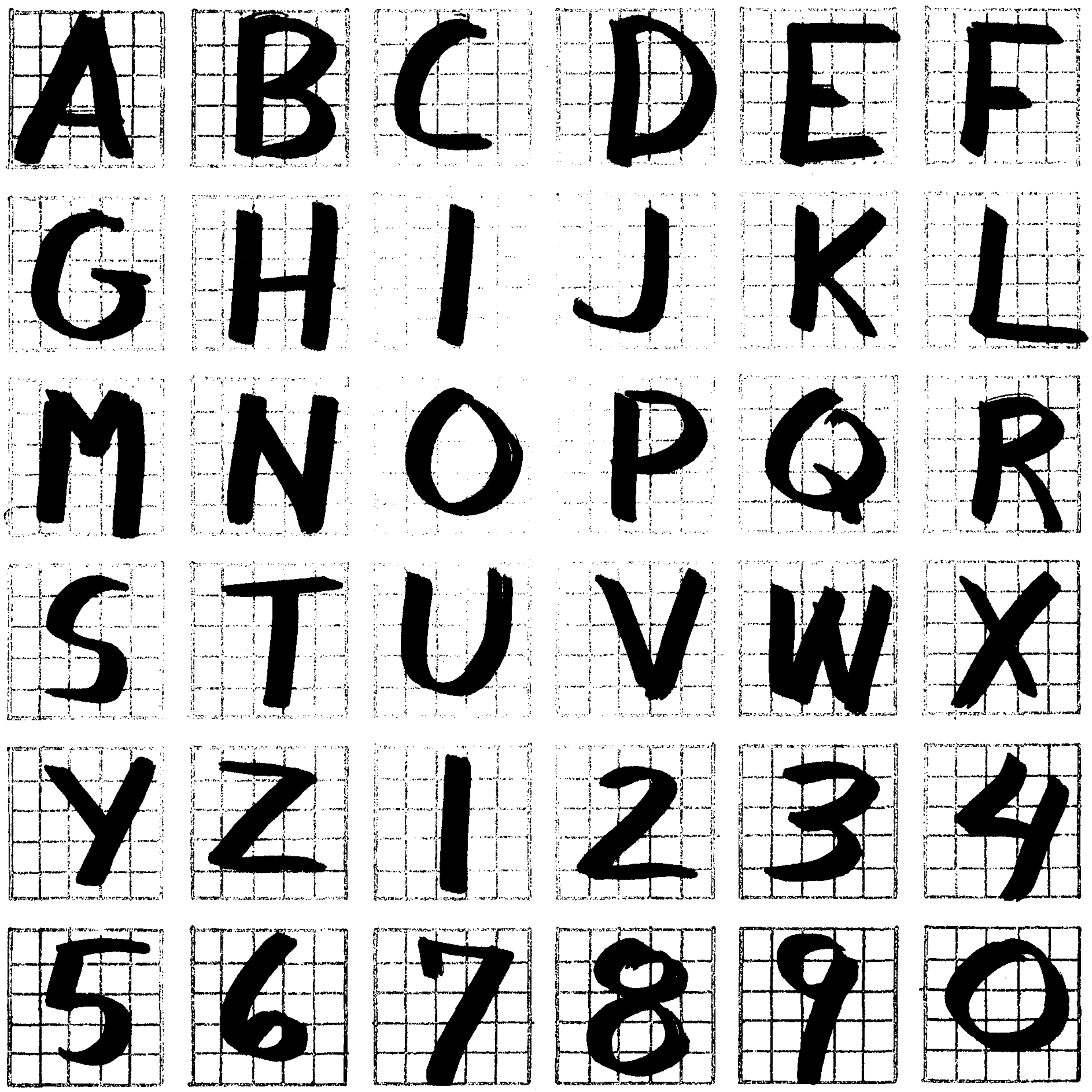
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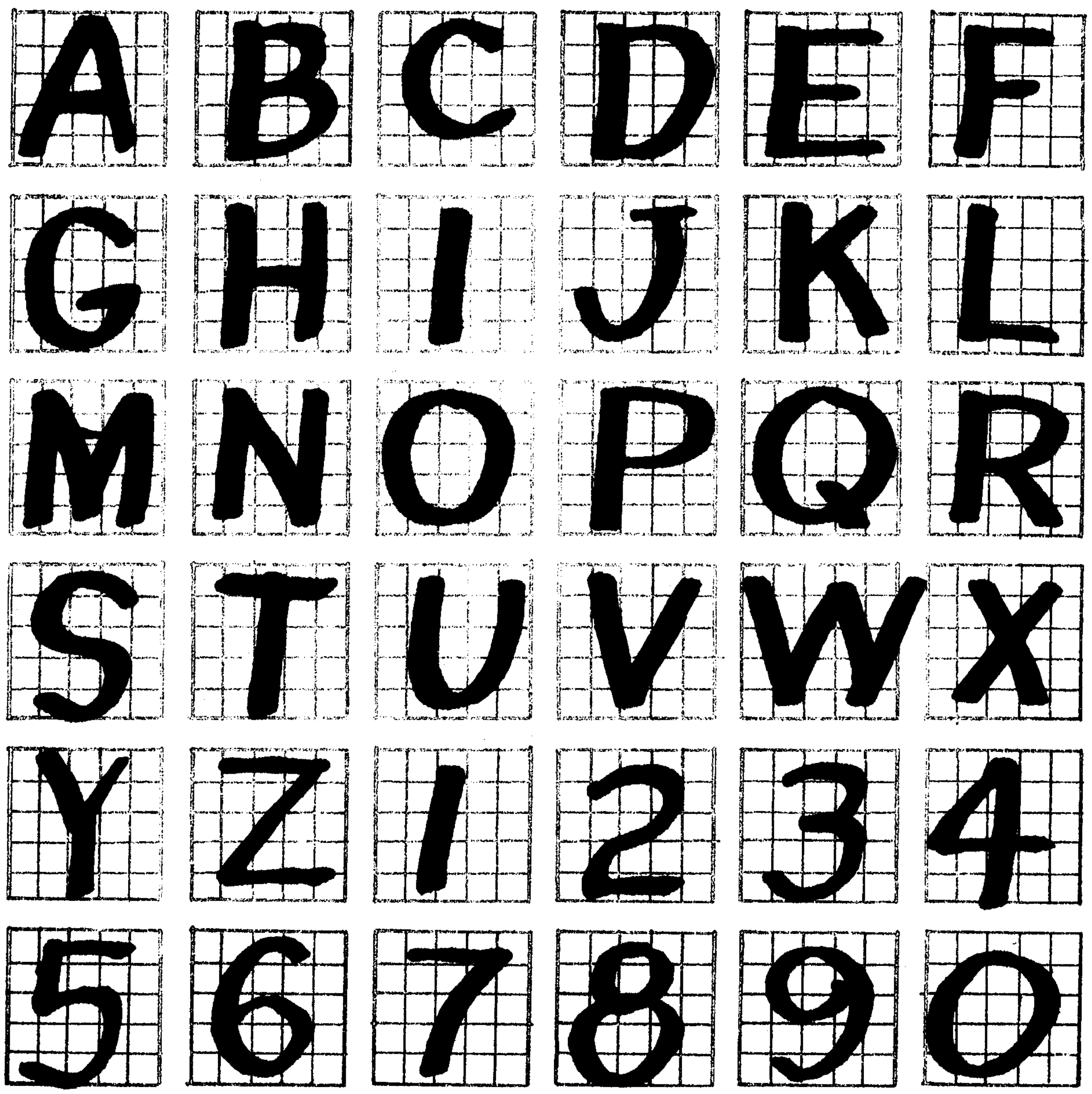
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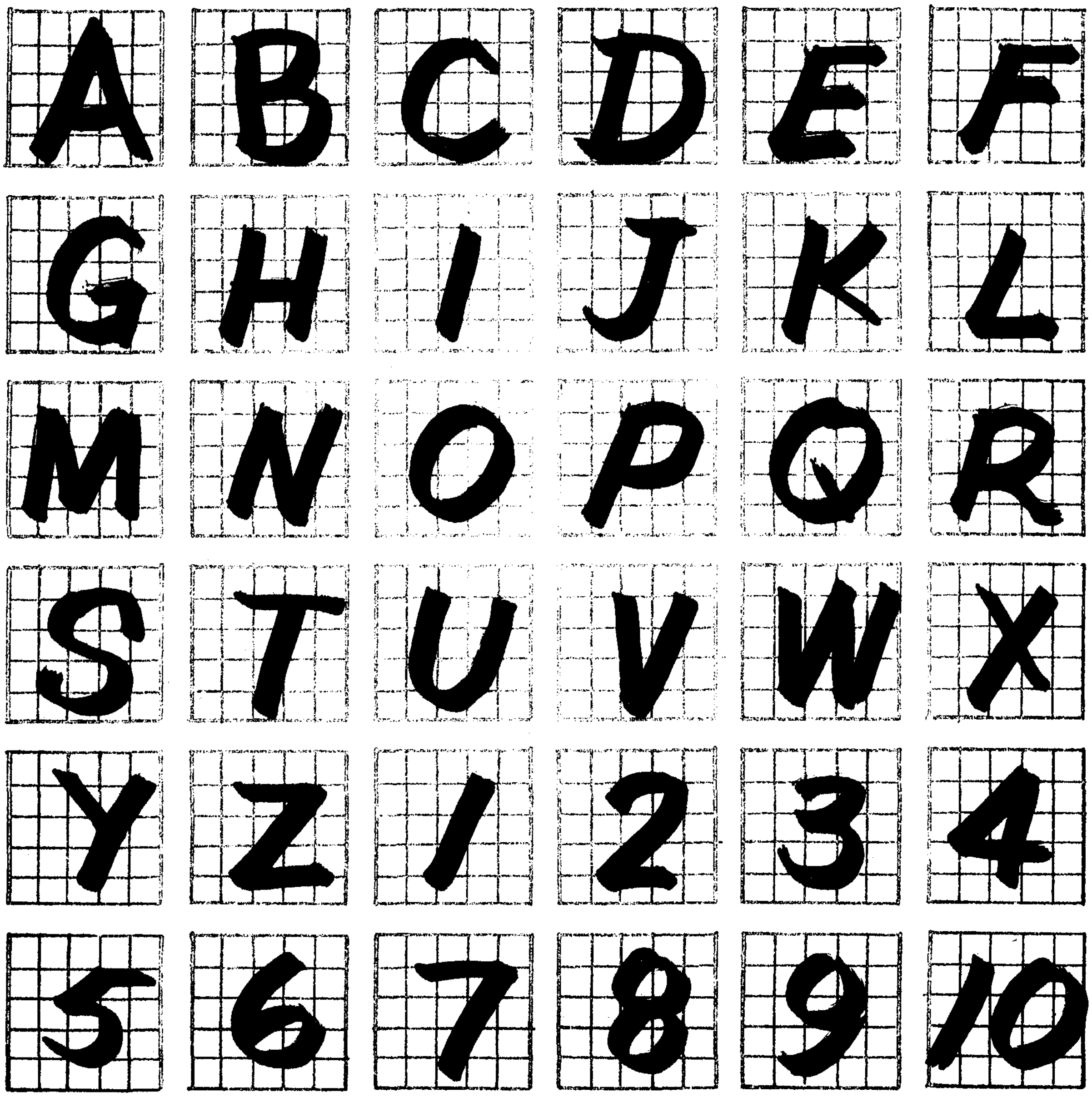
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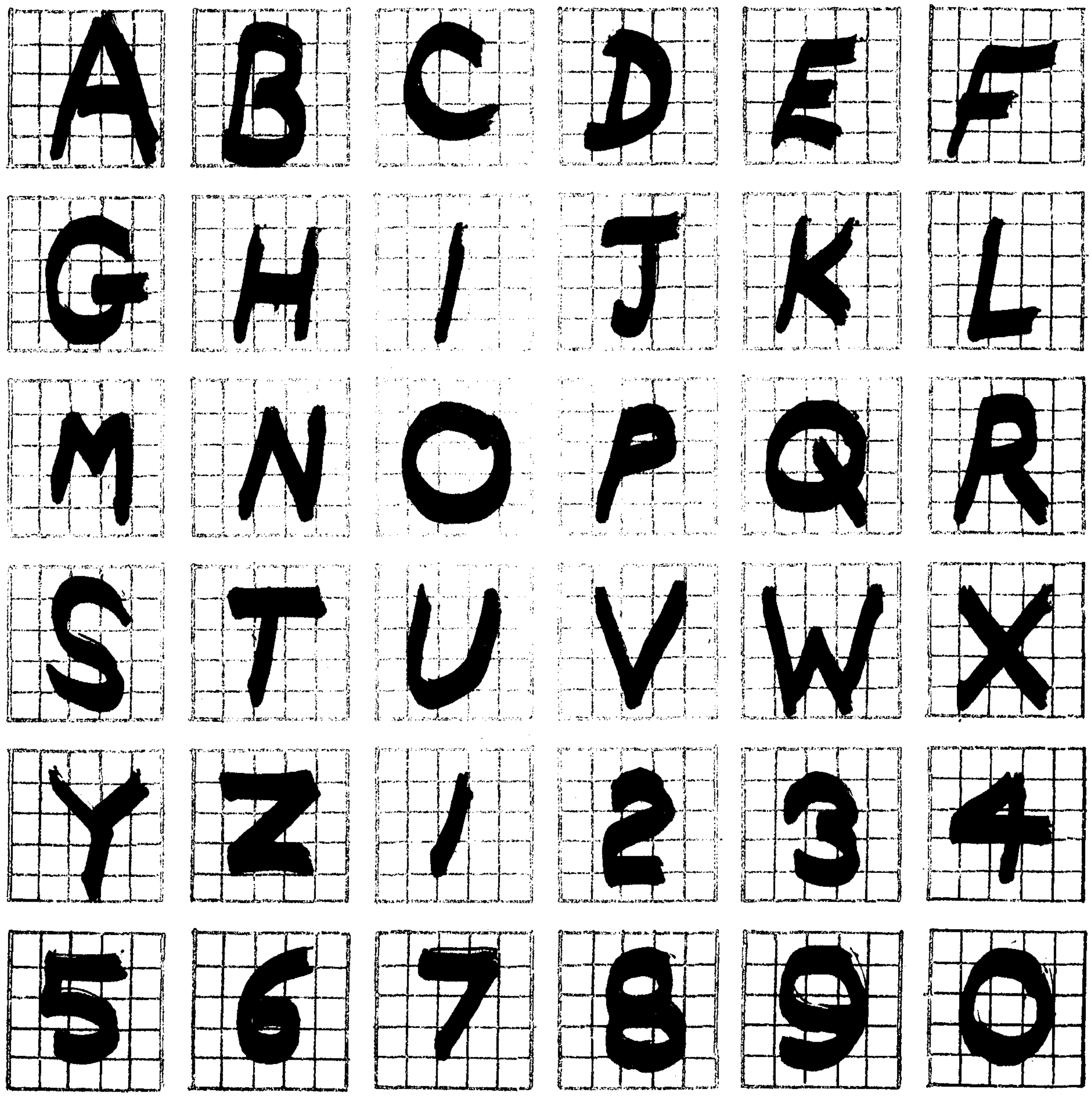
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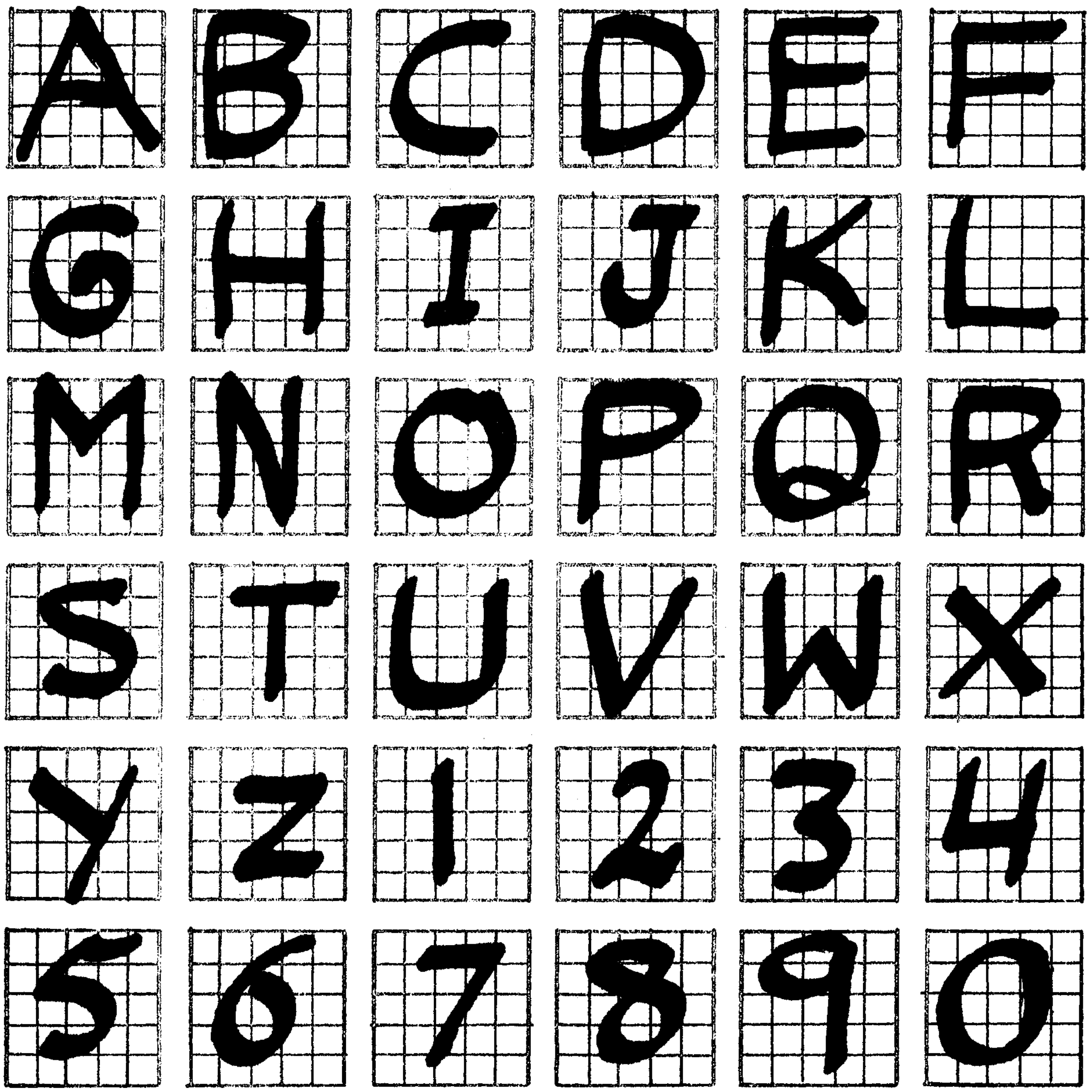
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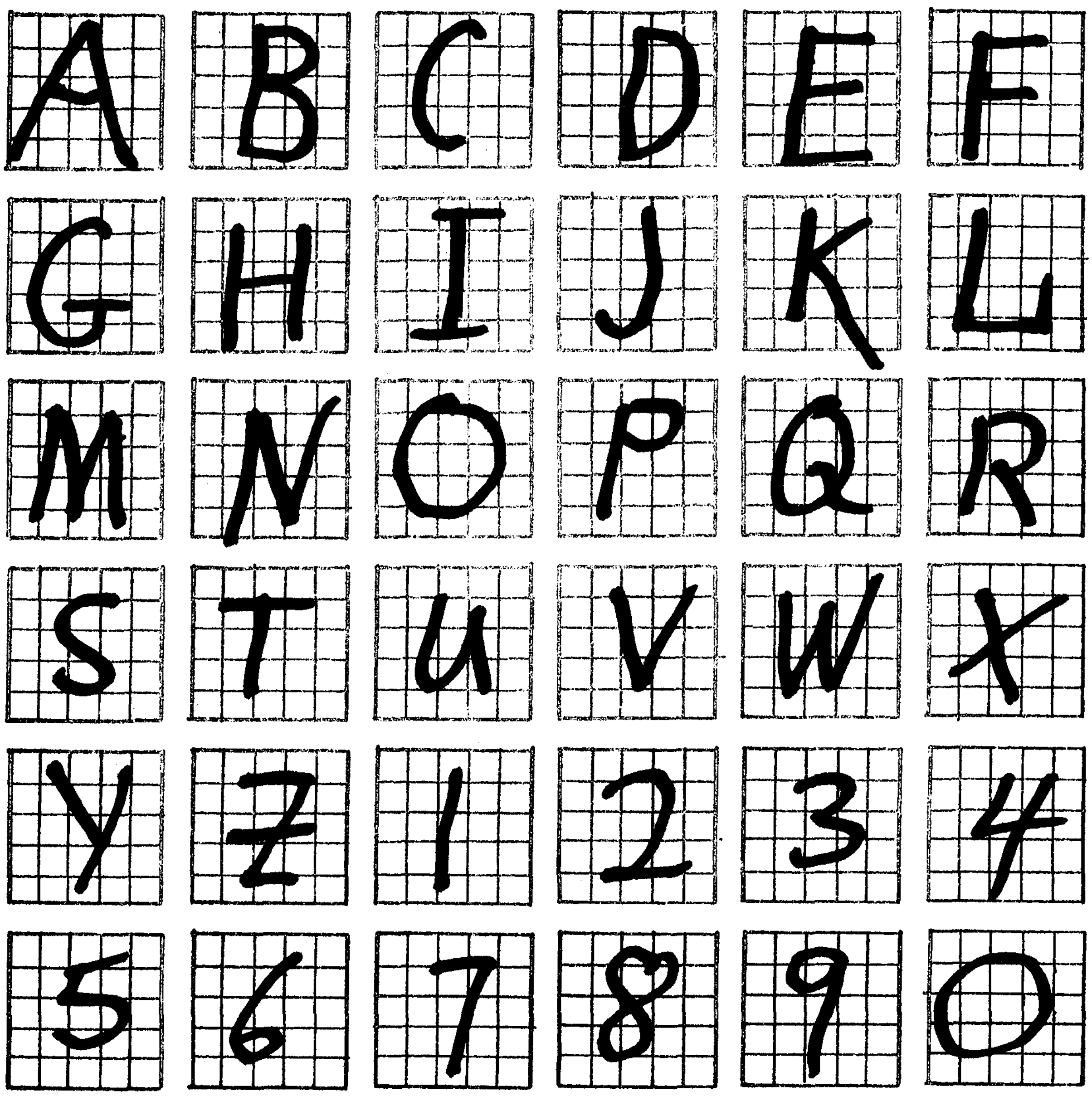
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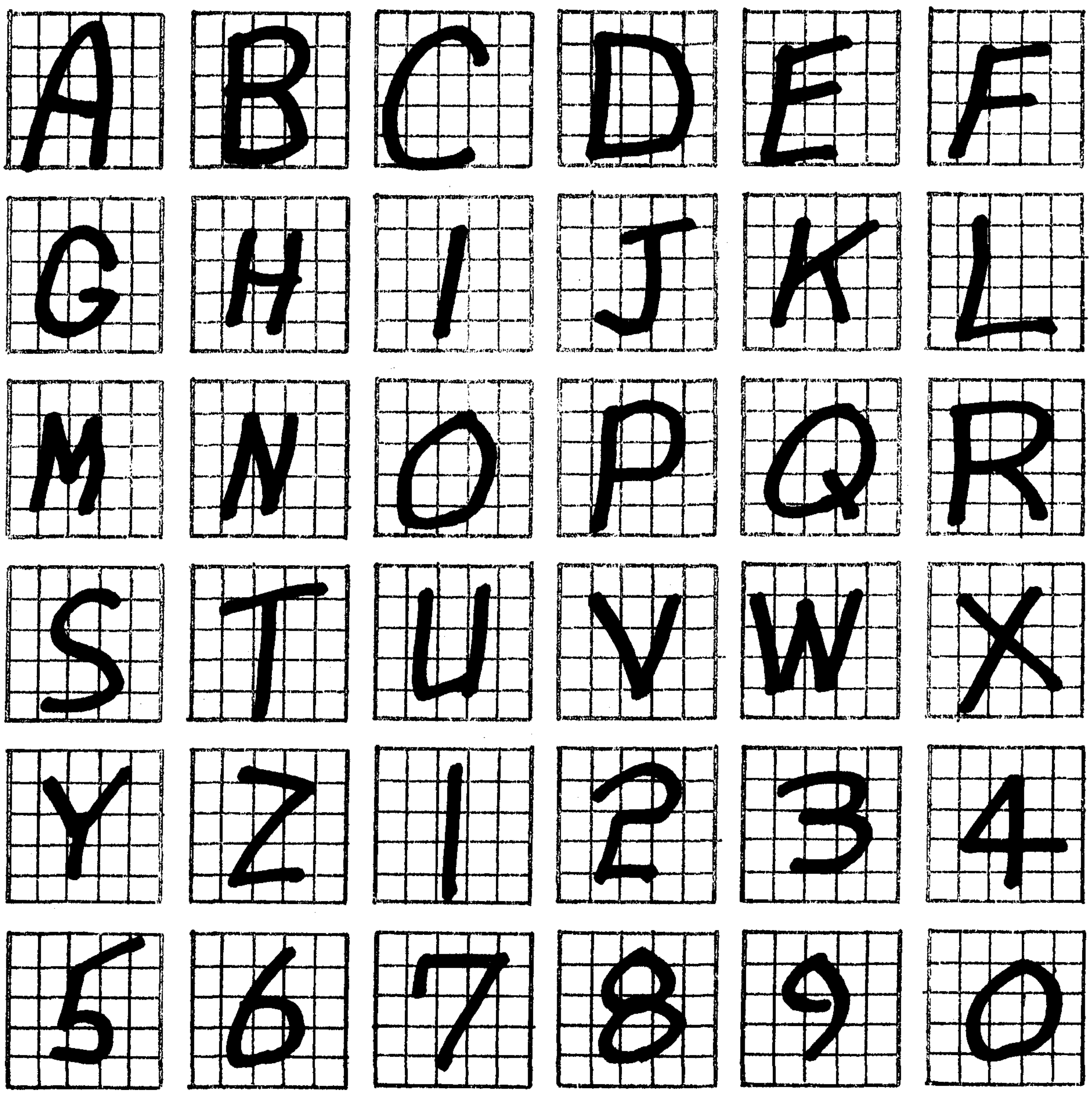
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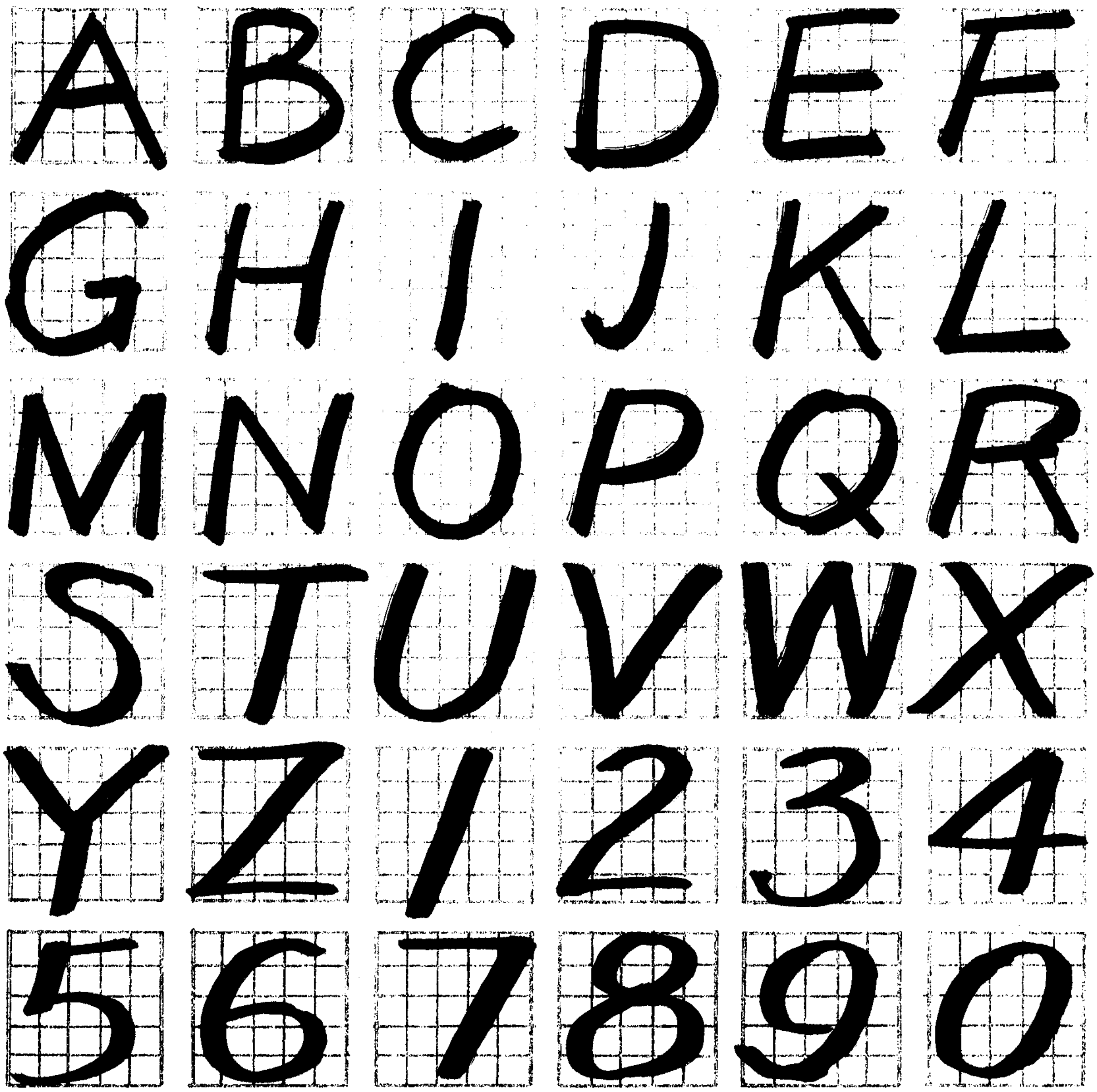
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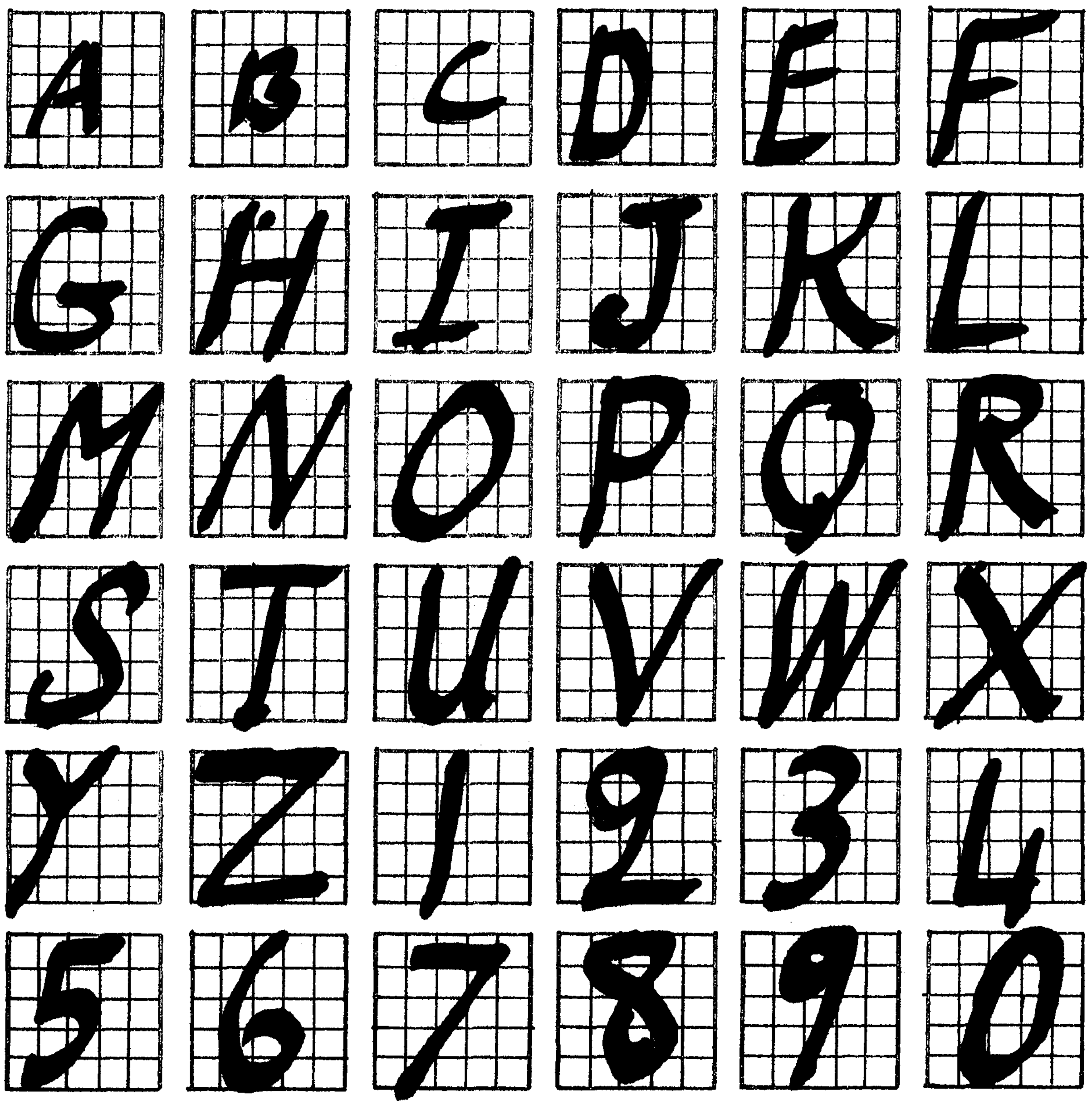
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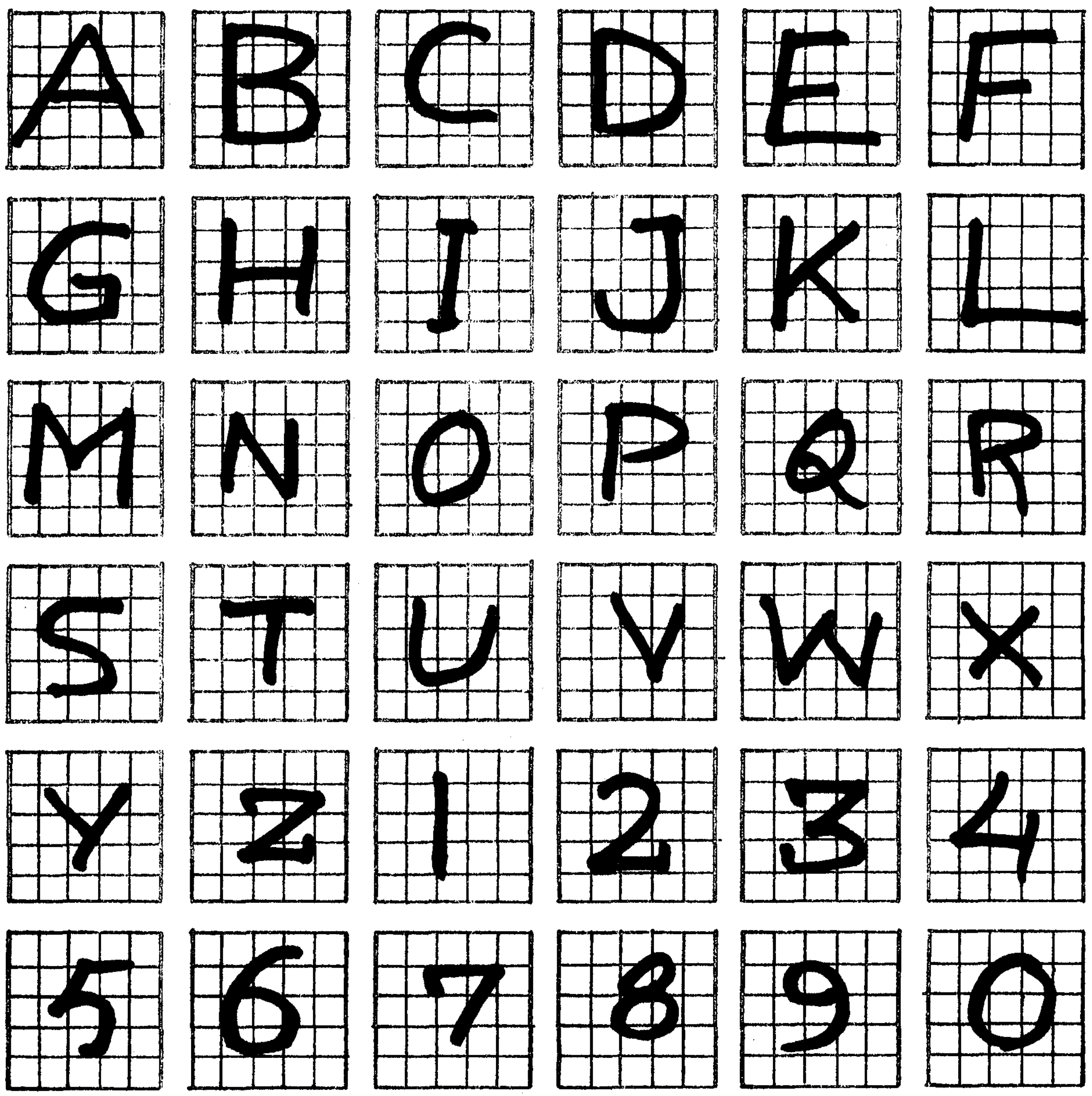
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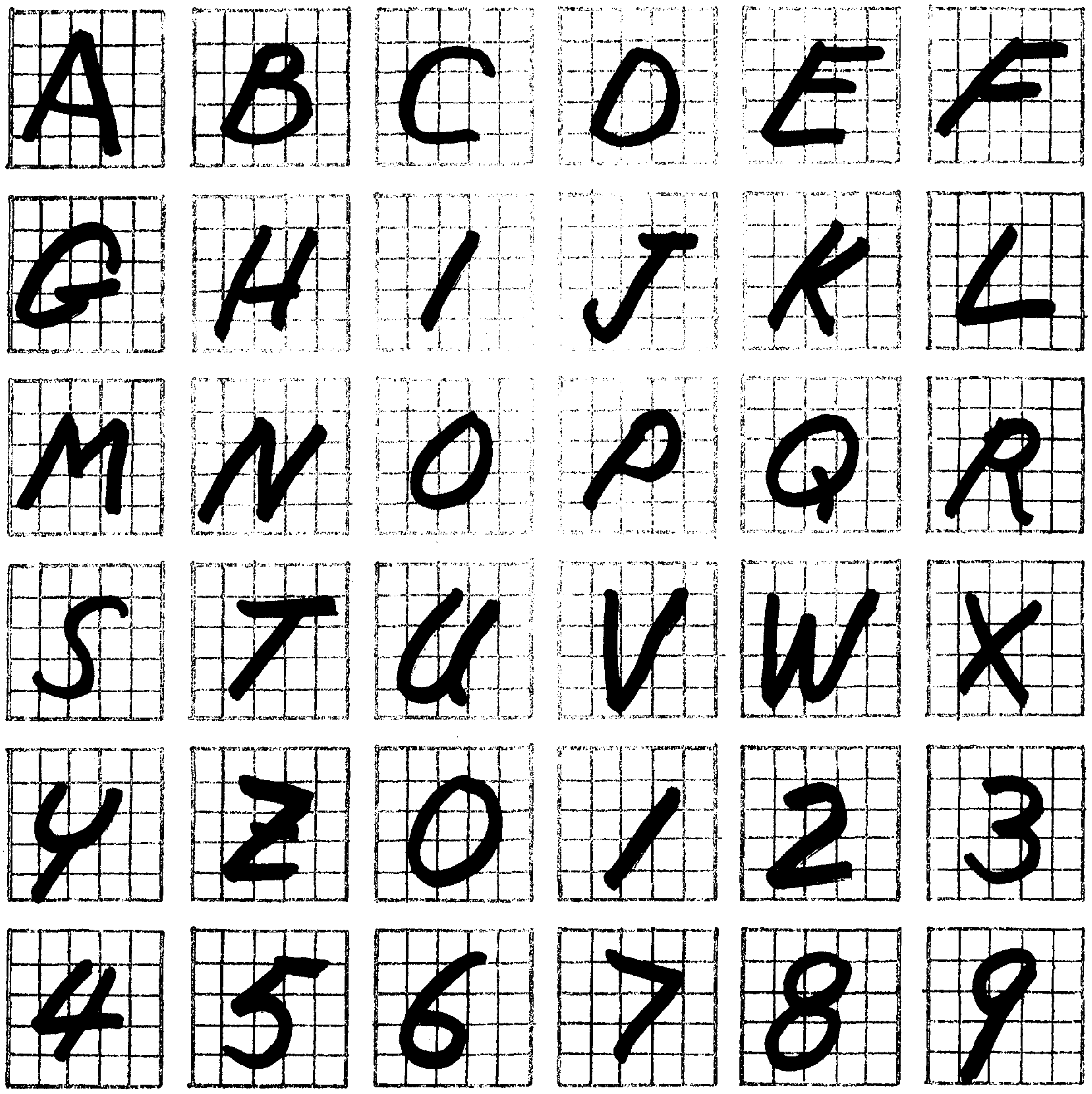
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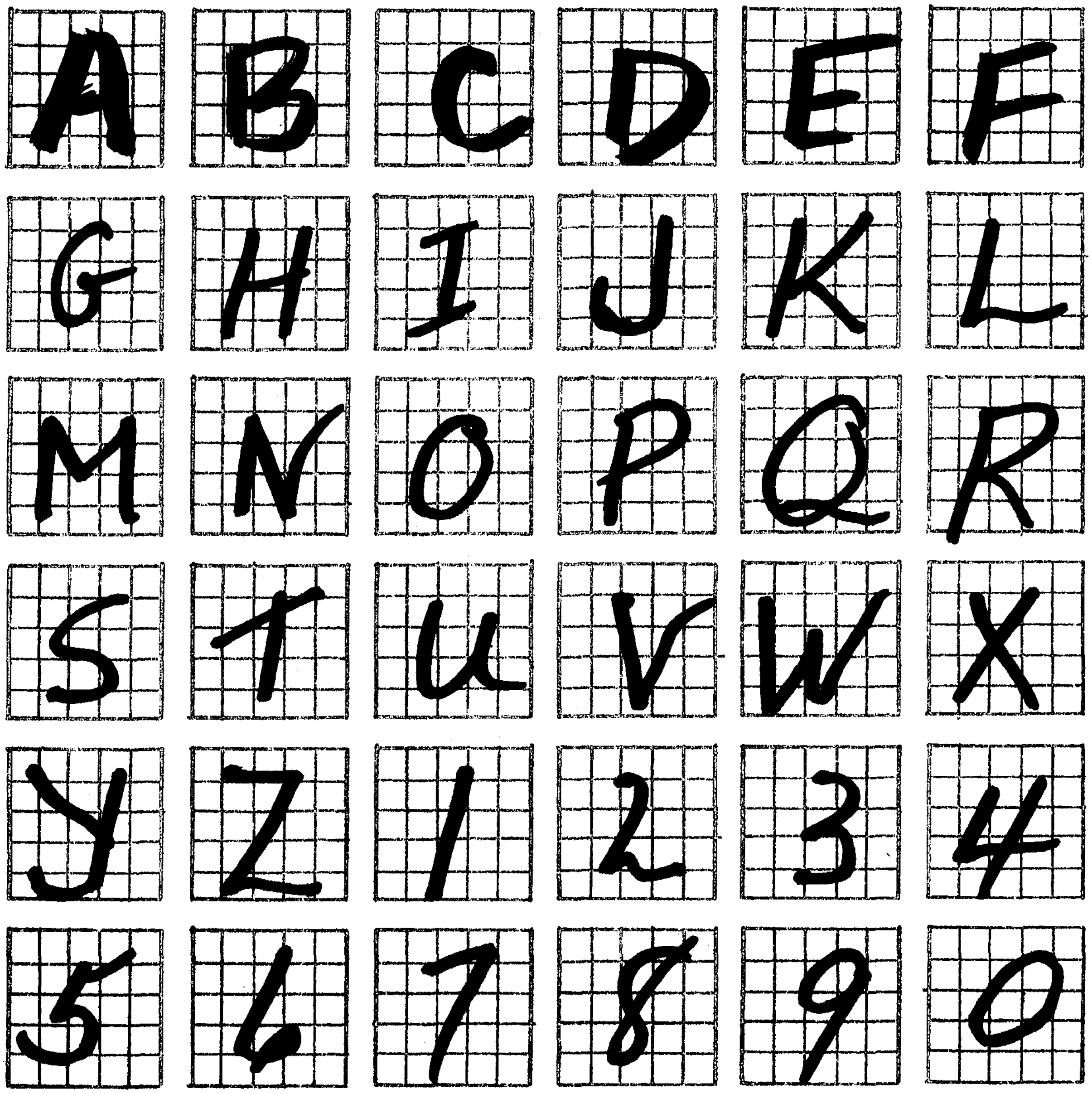
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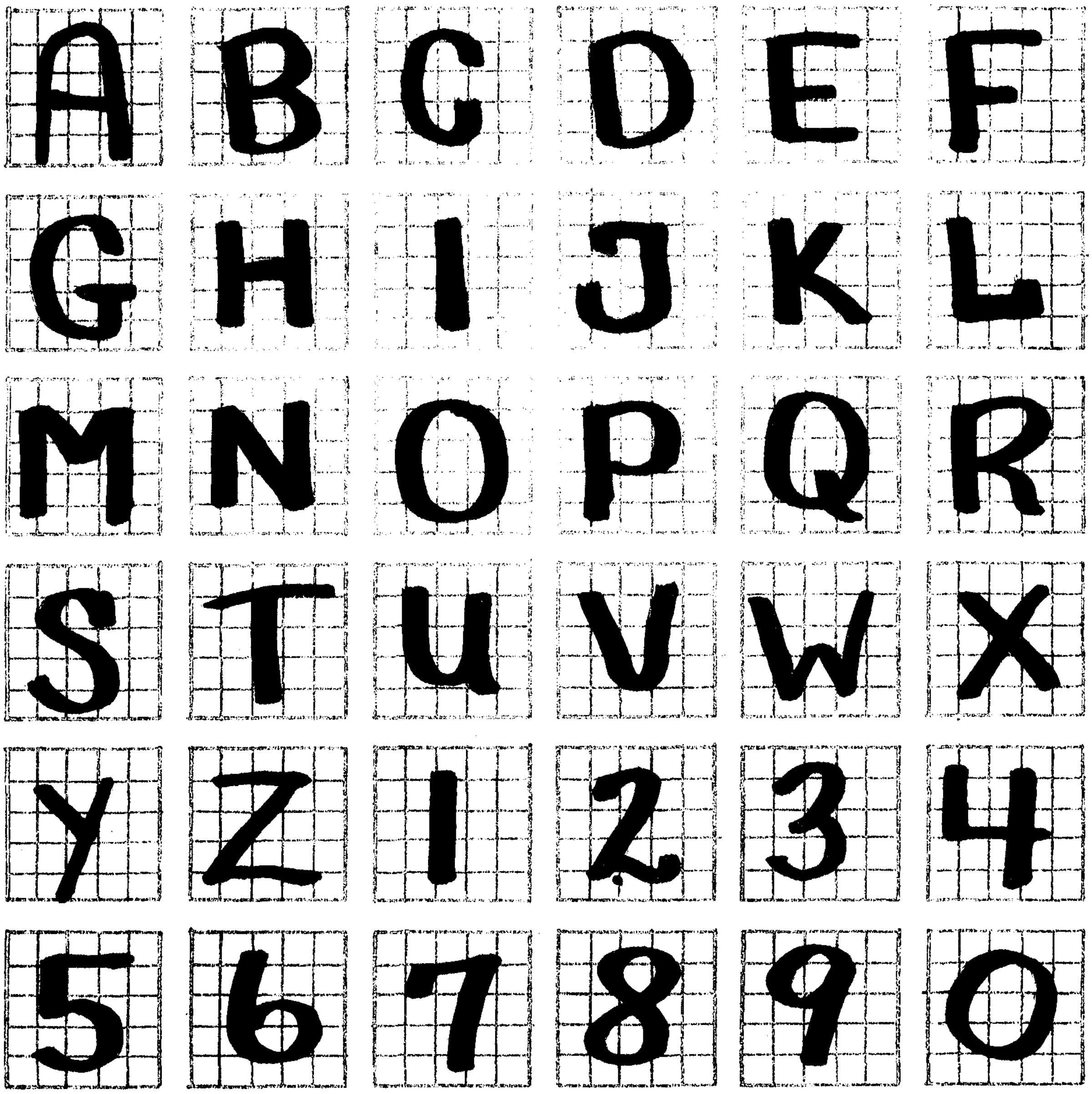
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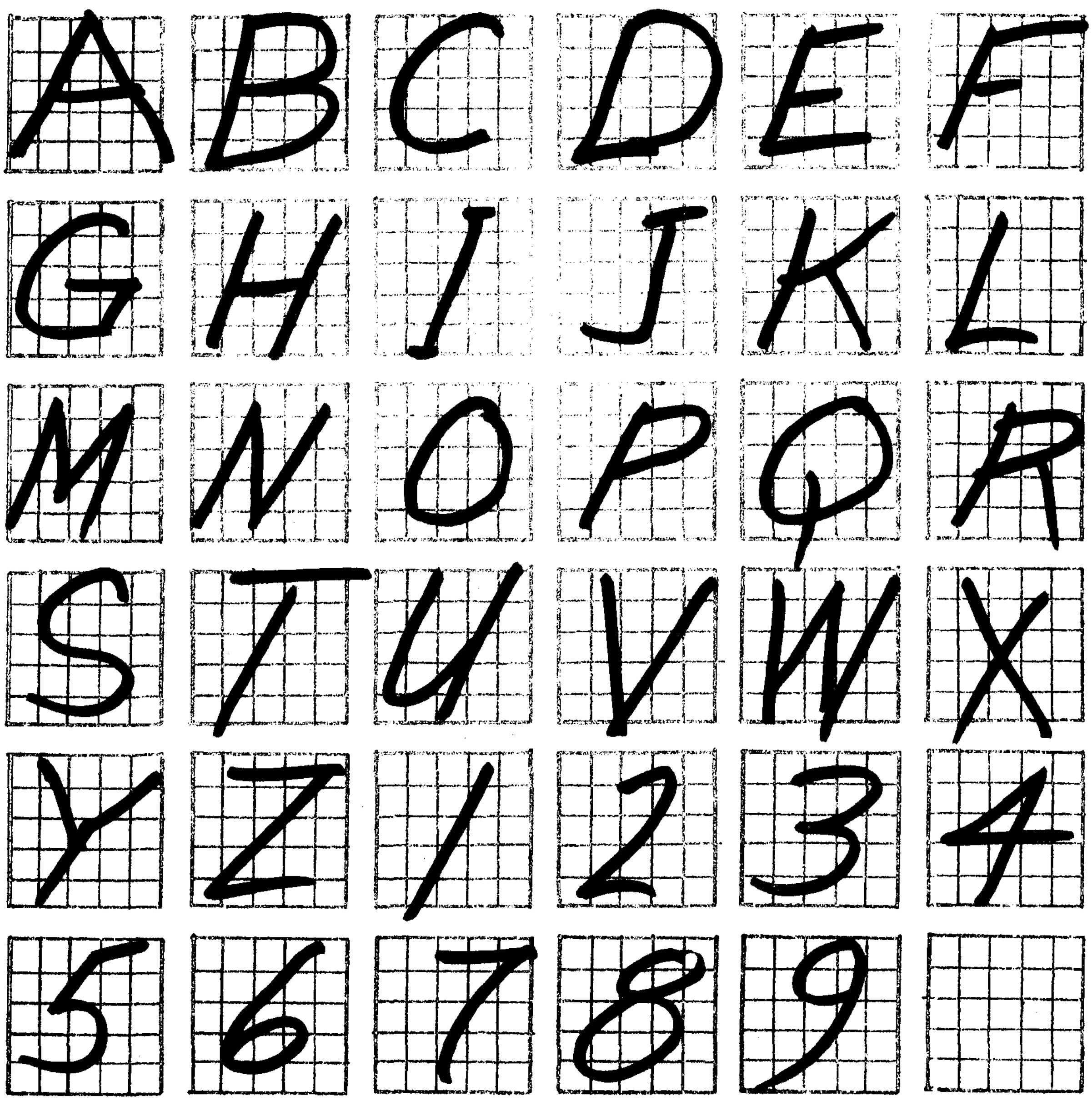
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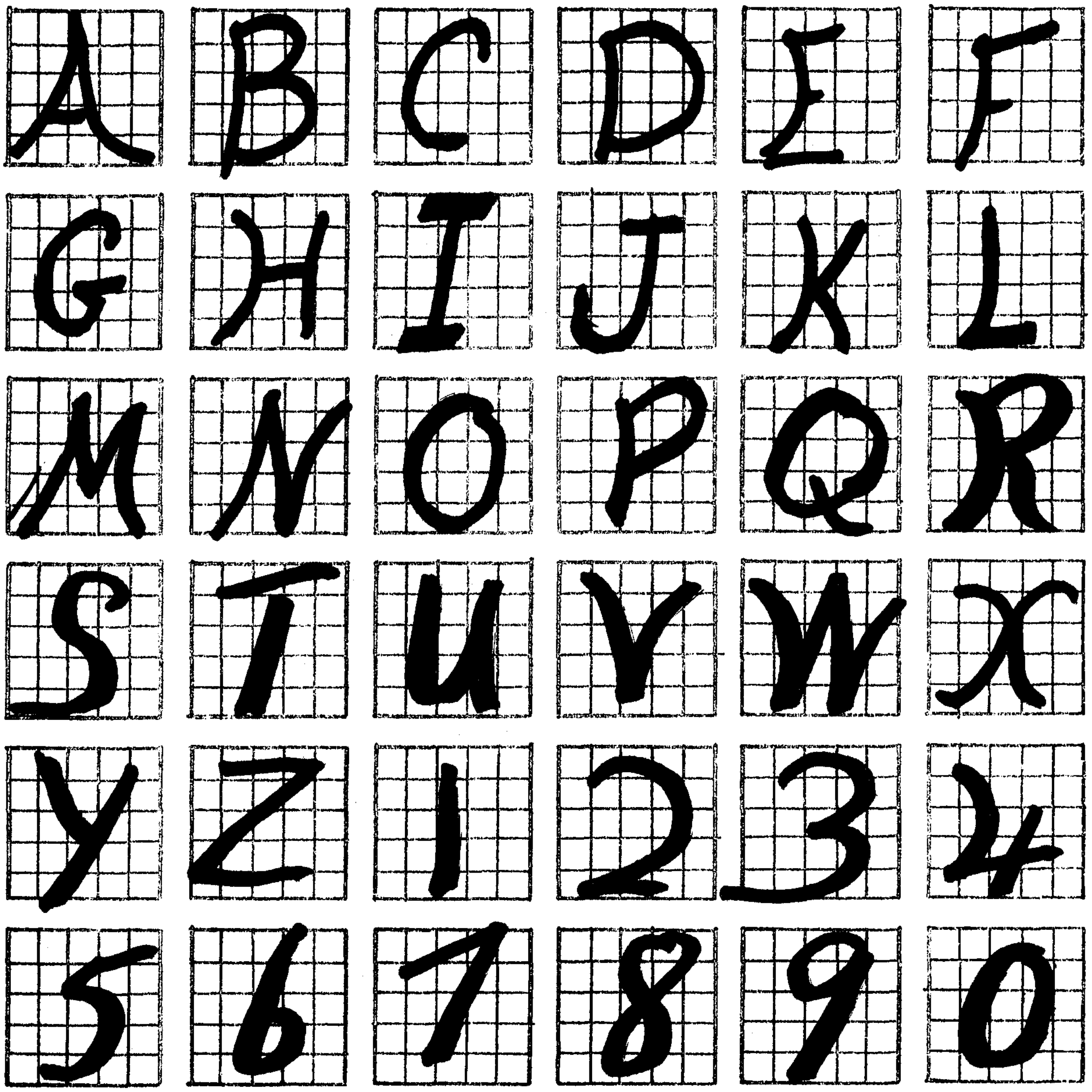
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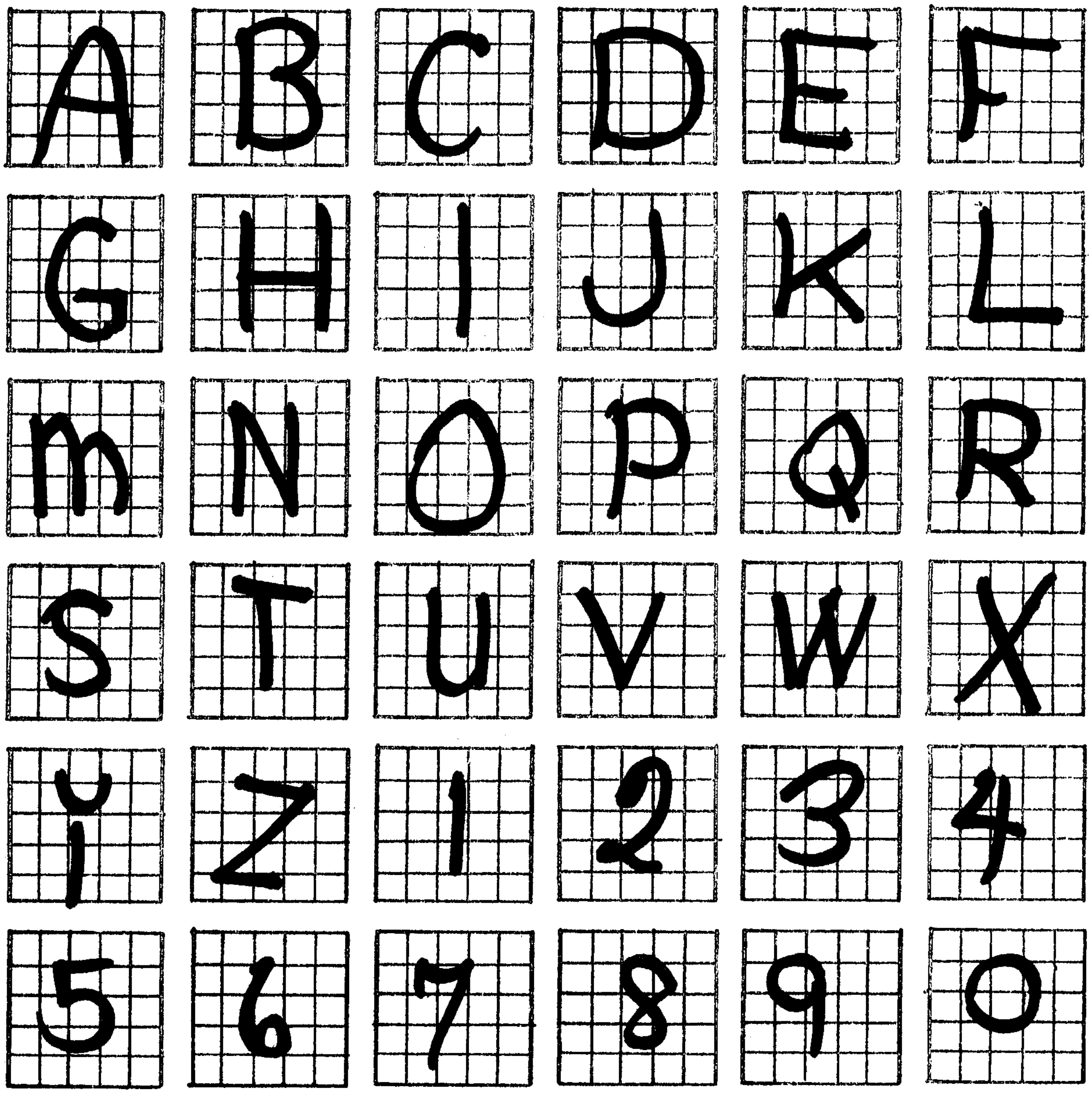
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