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AN INVESTIGATION INTO PATTERN INVARIANCE RECOGNITION CAPABILITIES OF THE HUMAN VISUAL SYSTEM

THESIS

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THESIS

Presented to the Faculty of the School of Engineering of
the Air Force Institute of Technology
Air University
in Partial Fulfillment of the
Requirements for the Degree of
Master of Science

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August 1963

Preface

This report is the result of my attempt to gain a better understanding of how the human visual system functions in performing pattern invariance recognition. An engineering approach is used in this investigation. I feel that the use of engineering methods of investigation in seeking solutions of biolbgical problems may sometimes be more feasible and more productive than the use of biological methods of investigation. In the simulation of a complex biological system, the use of digital computers seems particularly valuable, since the many trial and error steps required in constructing a physical model are reduced to the testing, revising, and retesting of computer programs.

I wish to express my gratitude to Captain Matthew Kabrisky (Ref 4) for the development of the basic model of a cortical cylinder and for his assistance in writing the computer program. Also, I wish to thank my wife and children for their patience and understanding during the time spent in making this investigation.

William L. Harrison

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Abstract

The purpose of this investigation is to find out how the human visual system performs pattern invariance recognition. A detailed study of the human visual system is made, a model of a portion of this system is derived, the model is simulated on a digital computer and tested to determine its pattern invariance recognition capabilities. The results indicate that the model recognizes patterns when translated slightly, rotated small amounts, or varied slightly in size and shape; however, its capabilities are far short of those of the human visual system. A recommendation is made for revising the model for further investigation.

I. Introduction

The human visual system is capable of recognizing learned patterns even though they have been translated in position, rotated through small angles, varied in size, or varied slightly in shape. Very little is known about the methods used by the visual system in achieving this pattern invariance recognition. The purpose of this research is to gain a better understanding of the functioning of the visual system in pattern invariance recognition.

This investigation does not include the functions of color vision or binocular vision, but only two dimensional black and white pattern recognition. No attempt is made to prove or disprove existing theories on the functioning of the human visual system.

It is intended that any simulation of any portion of the visual system will lie within the physical limitations of this system. To be considered an adequate simulation, a model of the visual system must be capable of recognizing learned patterns despite translation, small angles of rotation up to 25 degrees, large size variations, and slight shape variations of these patterns.

A wealth of literature has been written on the human visual system. Clinical studies and pathological investigations of the visual system have been carried on for many years. In recent years a great deal of scientific research has been conducted on various types of pattern recognition devices. This has led to much written material on various methods of achieving pattern recognition. No attempt was made to read all of this material, but only enough to gain a basic understanding of the detailed composition of the human visual system.

Any research leading to a better understanding of the functioning of the human visual pattern would be useful to persons in many fields. Astronomy, photography, ophthalmology, physiology, medicine, and computer design are only a few of the fields which would benefit from this knowledge. The visual system is the most important single source of information for the brain, since some 38% of all fibers entering or leaving the central nervous system do so by way of the optic nerves (Ref 8:301).

There are several possible methods which could be used in investigating the visual system. Surgical and electro-chemical techniques could be used to probe the visual system of suitable guinea pigs, trace the paths of information flow, and observe the visual effects of blocking certain portions of the visual system. This method would be more suited to a physiologist than an electrical engineering student.

A second method would be to use a combination of optical and photographic techniques to build a machine of lenses, filters, screens, and pattern storage devices, patterned after the visual system, in an attempt to duplicate the pattern invariance recognition capabilities of the eye-brain system. This method would require an extensive knowledge of the field of optics and some expense in the purchase of optical devices.

A third method would be to use digital computer simulation techniques to simulate the eye-brain system in an attempt to duplicate the pattern invariance recognition capabilities of this system.

The third method mentioned above was the one used in this investigation. The primary reason for selecting this method was one of economy, since the only cost was the purchase of computer time. Computer simulation was also a more convenient method for an electrical engineering student to use.

The plan of attack followed in this investigation may be divided into five steps. In chronological order they are:

1. Conduct a study of the subcortical portions of the human visual system.
2. Conduct a study of the cortical portions of the human visual system.
3. Derive a model of the human visual system and program this model on a digital computer.
4. Develop testing procedures and test the model on a digital computer.
5. Evaluate the data obtained from testing the model to determine the pattern invariance recognition

capabilities of the model.

These five steps were followed in this same chronological order in writing this thesis.

II. The Subcortical Portions of the Human Visual System

Included in the subcortical visual pathways are all the nerve structures from the retina of the eye to the cortex of the brain (see Fig. 1). The primary path for information flow from the eyes to the cortex is from the retinae of the eyes to the optic chiasma via the optic nerves, then to the lateral geniculate nuclei via the optic tract, then to area 17 of the visual cortex via the visual radiation. There are some side branches from this main path, but they are more related to the various mechanical movements of the eye than to the act of pattern recognition. Only the primary paths from the eyes to the cortex of the brain will be discussed in this chapter.

The retina is the membrane at the back of the eye which acts as the actual photoreceptor organ. It is composed entirely of nervous tissue and blood vessels, and is actually an outgrowth of the frontal end of the brain formed during the early period of embryonic life. Light entering the eye through the cornea and lens and falling on the retina, causes it to emit electrical pulses, which, when transmitted to the brain, result in the act of perception or vision. The two types of elements in the retina which act as photocells are the rods and cones, so named because of their shapes. The rods are more sensitive to light than the cones and are the primary source of night vision. The cones are associated

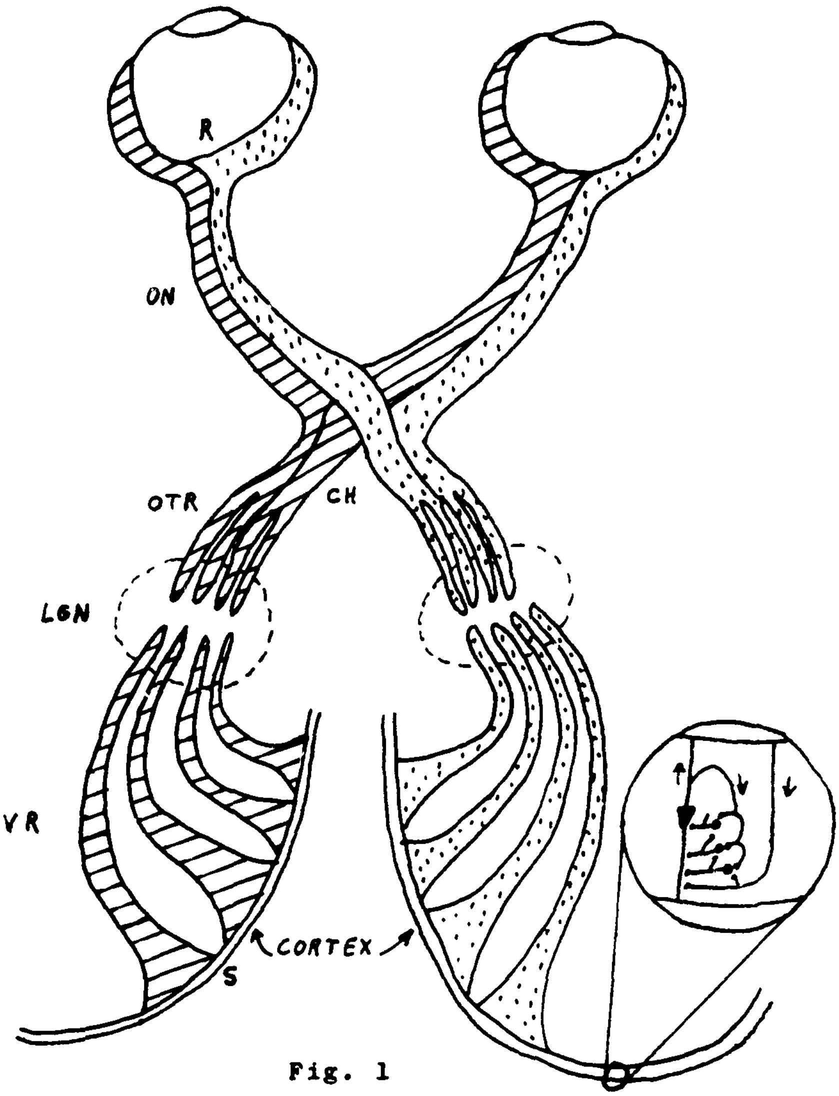


Fig. 1

Subcortical Visual Paths

This is a diagram of the subcortical portions of the human visual system, including the retinae (R), optic nerves (ON), optic chiasma (CH), optic tracts (OTR), lateral geniculate nucleus (LGN), visual radiation (VR), and striate area (S) or area 17 of the cerebral cortex. An enlarged section of the cortex is shown.

(From Ref 8:289)

with day vision. Rods and cones are interspersed throughout the retina with two exceptions. There are no rods or cones at the point where the optic nerve is connected to the retina. This results in a blind spot in the field of view. There is also a small pit or depression at the point near the center of the retina in which only cones are located. This pit is called the fovea and is located at the center of the field of vision. This is the center circle in the retina in Fig. 2, although it actually occupies a proportionately smaller area in the retina than drawn in the figure. Outside the fovea, the retina is made up of both rods and cones, with the rods becoming more dense and the cones more sparce moving towards the periphery of the retina. The fovea is the area of highest visual acuity. Here the cones are packed very close together and are 1 to 1.5 microns in diameter. Near the periphery of the retina the diameter of the cones is 6 to 8 microns. In the eyes of certain species possessing extremely high visual acuity, for example, the golden eagle, the thinnest cones in the fovea are approximately 1/3 micron in diameter (Ref 8:226).

In Fig. 2 is seen a mapping of the field of view in each retina. Each retina is divided into quadrants, as is the foveal area in each retina. The extreme left and right edges of the field of view (a, d, b, and c) are the monocular portions of vision and appear on only one retina. The remaining portions of the field of view,

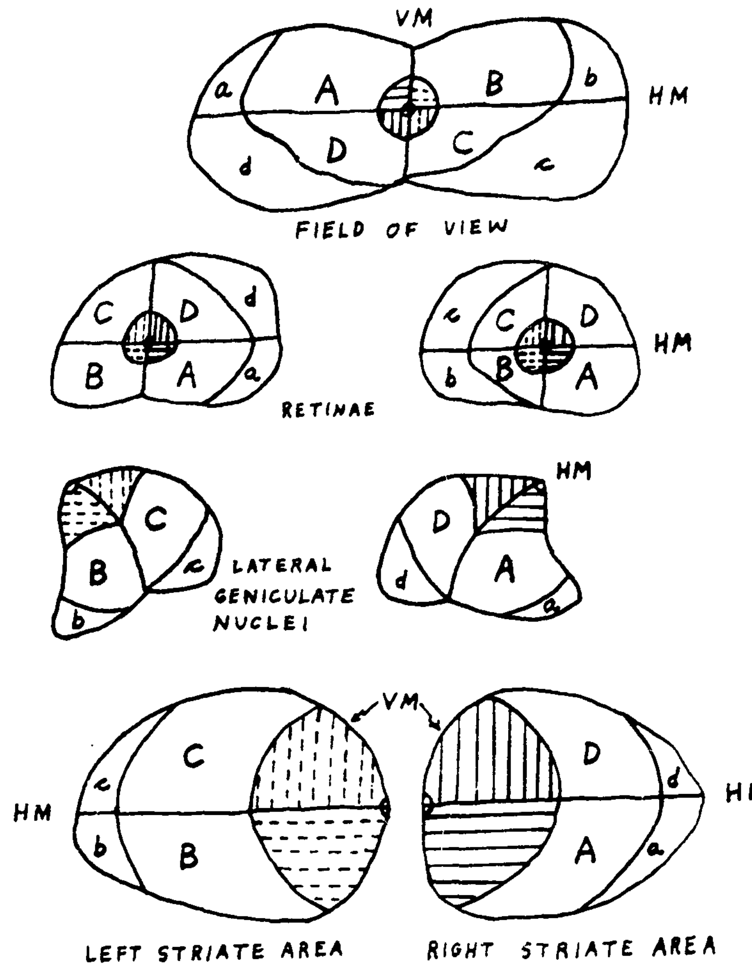


Fig. 2

Subcortical Visual Centers

This diagram shows the topographic representation of the field of view and the left and right retinal surfaces in the lateral geniculate nuclei and area 17 of the cerebral cortex. The vertical meridian (VM) and the horizontal meridian (HM) are shown in each visual center.

(From Ref 8:431)

quadrants A, B, C, and D, are projected to corresponding quadrants on each retina. Similarly, the four quadrants in the center of the field of view are projected to corresponding quadrants in the fovea of each retina. The number of rods and cones in the retina is approximately 10^8, and the number of fibers in the optic nerve is approximately 10^6, thus, each receptor cell cannot send individual information to the brain. In the peripheral region there are many rods or cones connected through integrating neurons to single nerve fibers, but in the rodless center of the fovea, where detailed vision originates each cone is connected through a neuron to a single fiber of the optic nerve. In this small rodless area measuring about 500 microns across, there are about 35,000 cones. This area corresponds to 1 degree 50 minutes of arc in the field of view, yet it is probably the most important part of the retina. The fact that each individual cone in this area can send information to the brain is undoubtedly related to the detailed vision occurring in this area.

The 10^6 fibers from the retina are bundled together to form the optic nerve. Each of these fibers is actually the axon of a retinal neuron. The two optic nerves meet at the optic chiasma, where the fibers from the nasal half of each retina cross and join the fibers from the temporal half of the opposite retina to form the optic tracts (see Fig. 1). Thus the left optic tract is composed of fibers from the left half of each retina and the right optic tract is composed of fibers from the right half of each retina. The optic tracts continue on to the lateral geniculate nuclei in the thalamus of the midbrain.

The fibers of the optic tract terminate in six layers in the lateral geniculate nucleus. Fibers from corresponding points in each retina terminate in superposed positions in alternating layers. As shown in Fig. 2, the mapping of the retina is preserved in the lateral geniculate nuclei. The amount of area in the lateral geniculate nuclei devoted to fibers from the fovea is proportionately larger than the area of the retina occupied by the fovea. In the lateral geniculate nuclei the horizontal meridian has been shifted slightly, as shown in Fig. 2. Also, a proportionally smaller space is devoted to the fibers from the nasal periphery of the retinae, which is the area of monocular vision. The area devoted to the fibers from the upper quadrants of the retina is larger than that devoted to those from the lower quadrants.

Each fiber from the retina terminates in axosomatic synapses with a small nest of large neurons in the lateral geniculate nuclei. Fibers originating in these nests of large neurons comprise the paths, known as the visual radiation, which continue from the lateral geniculate nuclei to the cortex. Several types of neurons are found in the lateral geniculate nucleus. The primary type is composed of the large neurons upon which the vertical fibers terminate. There are also smaller neurons, called "association cells", each of which is synaptically related with approximately 12 of the large neurons (Ref 8:369-370). The most significant feature of the lateral geniculate nuclei is that the mapping of the retina is preserved both in the fibers which enter the lateral geniculate nuclei and in the fibers which depart the lateral geniculate nuclei in the visual radiation. As seen in Fig. 1, the fibers of the visual radiation lead directly to area 17 of the cerebral cortex. Here they terminate at points which topographically conform to the mapping of the retina (see Fig. 2). The portion of area 17 representing the fovea is proportionately larger than the area of the fovea in the retina. Also the peripheral portion of area 17 is proportionately smaller than the peripheral portion of the retina. In the retina the foveal units (cones) are very small, but they gradually increase in size in the peripheral regions. In area 17, where space is less severely restricted and the function of information processing demands a greater mass of the nervous substance in each unit, exactly the opposite is true. Here the units gradually increase in size from the peripheral to the foveal areas. The size of area 17 in man is, on the average, 2613 square millimeters. Since the area of the retina is approximately

350 square millimeters, the ratio of its area to that of area 17 is roughly 1 to 7 (Ref. 8:490).

The most significant fact gained from the study of the subcortical portions of the human visual system is that the retina is connected point by point to area 17 of the cerebral cortex in a manner which makes possible conformal mapping of the retina in area 17. The right half of each retina is mapped in area 17 of the right occipital lobe and the left half of each retina is mapped in area 17 of the left occipital lobe of the brain. The mapping of the fovea is accomplished by each cone being connected to a corresponding point in area 17; thus, an image falling on the fovea could be projected in great detail to area 17. A closer look at the terminations in area 17 of fibers from the lateral geniculate nuclei, and at further cortical portions of the visual system, will be taken in the following chapter.

III. Cortical Portions of the Human Visual System

In the preceding chapter, the fibers from the retina were shown to terminate in area 17 of the cerebral cortex. Before taking a closer look at these terminations, a discussion must be made of the general structure of the brain.

The brain consists of an upper main part, the cerebrum, and a lower small part, the cerebellum. Only the cerebrum is concerned in this investigation. The brain is enclosed in three membranes. The outer membrane, which is relatively thich and tough, adheres to the cranium. The inner two membranes are thin and soft. The innermost membrane closely adheres to the surface of the brain, penetrating all dents and depressions of the cerebral surface. It contains the blood vessels which are the principal avenue used to supply blood to the brain. The brain is composed of two kinds of substance, grey matter and white matter. Most of the grey matter forms the relatively thin outer shell of the brain called the cortex. This cortex is composed of countless neurons and their thin fibers, and of a dense network of minute blood vessels and capillaries. This is apparently the portion of the brain where the "higher" functions of information processing are performed. The white matter forms the inner or subcortical portion of the brain and is composed principally of nerve fibers of varying thickness. These fibers could be considered as transmission lines connecting various portions of the cortex.

The cerebrum, which is the largest and uppermost part of the brain, is seperated into a left and a right hemisphere. The lobe at the rear of each hemisphere, the occipital lobe, is the location of area 17 (see Fig. 3). The cerebral cortex was mapped into functional areas and numbered by Brodmann. The fibers of the visual radiation terminate wholly within area 17 of each side of the brain. There is no crossover of fibers in the visual radiation. The fibers from the left lateral geniculate nucleus terminate solely in area 17 of the left occipital lobe, and those from the right lateral geniculate nucleus terminate only in area 17 of the right occipital lobe (Ref 8:403-405).

The cortex in area 17 is thin compared with other cortical areas. The thinnest part of area 17 is in the foveal regions. Area 17 is, on the whole, much richer in neurons than the remainder of the cerebral cortex. Also, the size of its neurons is much smaller, the space between its neurons less, and the distribution of its neurons more uniform than in other cortical areas. A vertical section through the cortex in area 17 shows eight separate parallel layers, five of which are rich in neurons and three of lesser density (Ref 8:496). These layers are parallel to the cortical surface and

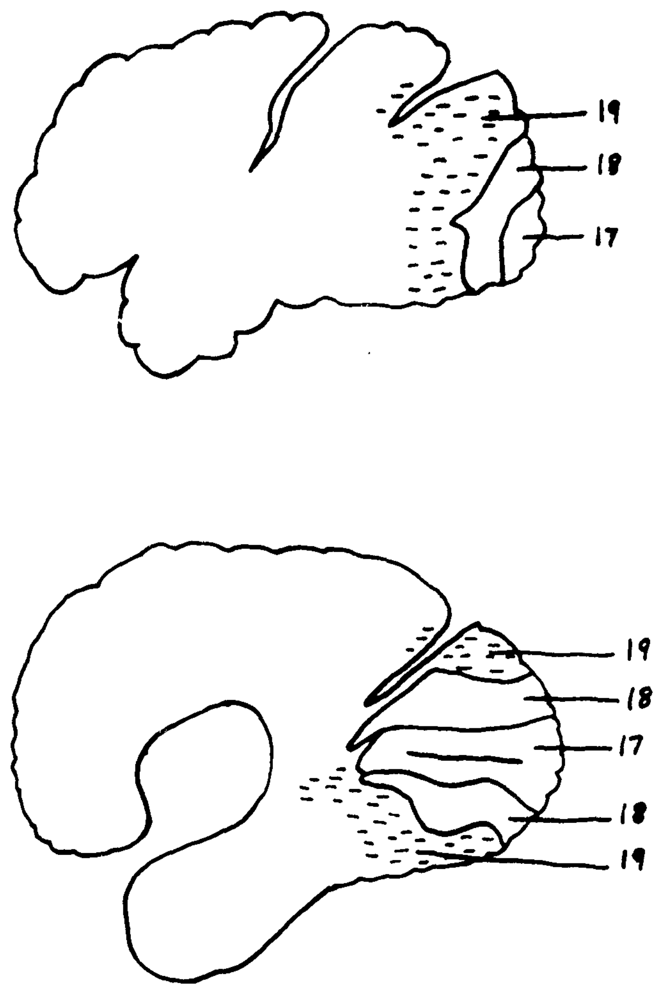


Fig. 3

Cortical Visual Centers

This is a sketch of the human cerebral cortex showing the location of the visual centers, area 17, area 18, and area 19, as numbered by Brodmann. The upper figure is a side view of the left hemisphere and the lower figure is a cross section, taken lengthwise through a vertical plane, of the right hemisphere.

(From Ref 8:492)

are numbered 1, 2, 3, 4a, 4b, 4c, 5, and 6, with layer 1 being the outermost layer. The fibers of the visual radiation enter the cortex from underneath and pass through layers 6, 5, and 4c to terminate in layer 4b (Ref 8:519-521). Layer 4b is composed of neurons which are connected by a dense network of short horizontal fibers. Although the fibers of the visual radiation are the principal ones terminating in layer 4b, there are indications of other fibers terminating in this layer (Ref 8:523).

In layer 1 there are few neurons, but there are many fibers from neurons in lower layers. In layer 2 there are several types of neurons with short fibers, one of which has vertical fibers extending up into layer 1 and down as far as layer 4b (Ref 8:527). In the foveal portion of area 17 in an adult Rhesus Macaque monkey, there are neurons in layer 2 with axons which descend to the subcortical matter (Ref 8:531). The neurons in layer 3 are of several types, which in general resemble those in layer 2. However, some of them have fibers which descend to the subcortical portion of the brain (Ref 8:527).

The neurons of layer 4 appear more diversified than those in other layers. They vary a great deal in the shape, size, and distribution of their bodies and in their dendritic and axonal expansions (Ref 8:527). The most conspicuous neurons in this layer are large solitary ganglion cells whose bodies and dendrites are mostly oriented horizontally or obliquely. Their axons descend toward the subcortical substance. Whether all of these leave area 17 is questionable (Ref 8:527). Another type of neuron in layer 4 has vertical fibers which fuse superposed segments of layers 4a, 4b, 4c, and 5 into functional units whose elements are activated simultaneously (Ref 8:527). Other large neurons, residing in the zone between layers 4b and 4c, have dendrites which radiate in all directions and interconnect relatively large segments of these sublayers into functional units (Ref 8:527).

Layers 5 and 6 are also populated by numerous neuron varieties. Although their detailed connections are not well known, it seems that more neurons here are oriented in a horizontal direction than in the layers above (Ref 8:531).

As stated before, the terminations of fibers of the visual radiation are in layer 4b of area 17. Each fiber spreads horizontally in this layer for short distances. In the foveal portion of area 17 of a baby Rhesus Macaque monkey, the horizontal spread of an individual fiber measures 100 to 150 microns. This, computed for the foveal portion of area 17, would give at least 10,000 to 15,000 independently stimulable functional units to each vertical foveal half. This is in fair agreement with the number of cones populating the foveal territory of the retina (Ref 8:533). This seems to indicate the connection of each cone in the fovea to a corresponding functional unit in the foveal portion of area 17. In the same foveal portions of the human area 17, the number of units would be correspondingly larger in order to satisfy the greater number of central foveal cones in the human retinae.

There are fibers from area 17 which pass through the subcortical substance before re-entering the cortex. These fibers have been traced by making minute lesions in area 17 of living monkeys. The axons from the neurons destroyed in these lesions will degenerate and may be traced to their terminations when the monkey is later sacrificed. Through this technique it has been found that there are three categories of interconnecting fibers from area 17. In the first category are the short intracortical fibers originating from the neurons in area 17 and terminating in the nearest neighboring neurons. These fibers, primarily in layer 4, have been discussed before. They connect each minute area to its immediately surrounding area within area 17. These fibers do not descend to the subcortical part of the brain.

The second category of fibers is composed of short subcortical fibers. From each minute point in area 17 a great number of these fibers descend to the subcortical substance, where they immediately spread in four directions and eventually re-enter the cortex in the same area 17.

Through these fibers each particular point of area 17 is connected both ways with a fairly large portion of area 17.

The fibers in the third category are somewhat longer subcortical fibers than those in the second category. From each point in area 17, they descend to the subcortical substance. They continue beneath the cortex to area 18 and area 19 where they re-enter the cortex and terminate (see Fig. 3). These fibers branch considerably at their terminations, thus, the area of these terminations is much larger than the area of origin in area 17. Also the large areas of termination in area 18 and area 19 of fibers from any two neighboring points in area 17 are overlapping. Briefly, each minute territory of area 17 is connected to a larger territory of areas 18 and 19, with a reciprocal overlapping of adjoining units. Since no other cortical areas of the same cerebral hemisphere receive fibers from area 17, it seems that the primary stream of transformed retinal impulses from area 17 reaches, as the next station, areas 18 and 19 (Ref 8:439). The connections from area 17 to areas 18 and 19 indicate that the point to point projection of the retina, heretofore observed in the visual system, is now lost. Undoubtedly, a more complex relation exists here.

Fibers from area 17 of one cerebral hemisphere to area 17 of the opposite cerebral hemisphere are either entirely absent or very poorly developed. Equally uncertain are direct connections from area 17 to parts of the midbrain. There also seems to be no direct fibers from area 17 to other principal sensory and motor regions of the same or opposite hemisphere of the brain (Ref 8:440).

The sense of vision in the brain is bound to the occipital lobes of both cerebral hemispheres. Area 17 appears to be the location of the visual sensations of a more elemental character, such as the perception of light and colors, and localization of external objects in space. Areas 18 and 19 seem to be a material repository of complex visual functions, such as visual memory of the shape, color, and movements of objects which have been observed, and of the symbols or meanings of these objects (Ref 8:453). Very little seems to be known about the functioning of the visual centers of the cortex or about the significance of the interconnecting fibers in the functioning of these centers. It is possible there are further connections from areas 18 and 19 to other areas of the cerebral cortex, although no information on such connections was found in this investigation.

Several significant facts have been gained from the study of the visual portions of the cerebral cortex. The fibers of the visual radiation terminate in layer 4b of area 17. In the foveal portion of area 17, these terminations indicate an independently stimulable functional unit of the cortex for each fiber and thus for each cone in the retinal fovea. Vertical fibers from neurons in layer 4 of area 17 fuse superposed segments of layers 4a, 4b, 4c, and 5 into functional units. Both of these facts seem to indicate that the basic functional unit of the foveal portion of area 17 is a vertical, cylindrical section of the cortex. Adjacent neurons in area 17 are connected by short intracortical association fibers. From neurons in layers 2, 3, and 4b, there are axon fibers descending to the subcortical substance below layer 6. A majority of these fibers spread in four directions and re-enter the cortex in area 17. Others continue outside area 17 and re-enter the cortex in areas 18 and 19.

This completes the study of the visual system. The next step is to apply the information gained here in the development of a digital computer simulation of this system.

IV. Computer Simulation of a Portion of the Human Visual System

This chapter includes the development of a model of area 17, an explanation of a flow diagram of the computer simulation of the model, and an explanation of the digital computer program for the simulation of the model. The goal it is hoped to achieve in this computer simulation is to obtain a model, patterned after the human visual system, which will possess the same pattern invariance recognition capabilities as the human visual system.

The digital computer used in this investigation was the IBM 1620. The maximum memory of 40,000 digits in this computer placed a substantial restriction on the simulation of the visual system. This limitation is not alleviated substantially by even the largest contemporary machines.

Since the retina is mapped point by point in area 17, it was assumed that very little pattern recognition is performed in the subcortical portions of the visual system.

A pattern falling on the retina is projected point by point to area 17 by way of neuron output pulses. A simulation of the visual system must include area 17 and contain a method of feeding a pattern into this area 17 in the form of pulses. The basic functional unit of the foveal portion of area 17 is postulated herein to be a cortical cylinder, which is stimulated by neuron pulses from a single cone in the fovea. It was decided to represent the foveal portion of area 17 as a square screen composed of 100 cortical cylinders in a 10 x 10 array (see Fig. 4). Each of these cortical cylinders would represent a basic functional unit of area 17 which might be called a "super cell", since it is composed of many nerve cells. The neuron pulse rate input to this unit from a foveal cone was simulated by feeding a signal level, quantized in units from 0 to 100, into the unit. The amplitude of the signal would correspond to the intensity of the light falling on the foveal cone, since in the actual eye-brain system, input stimuli are coded into neuron pulse firing rate. Black and white patterns falling on the fovea and being projected to area 17 was simulated by feeding appropriate signal levels, representing white, into various units in the 10x10 array and by feeding a level of zero, representing black, into all other units in the array.

As shown in Fig. 4, the coordinates K and J were used to locate each unit in the array. A simple bar pattern would be presented to the array by feeding a level of amplitude 50 into the units indicated by an X in the figure and a level of zero into all other units. Storage or memorization of the pattern was made possible by gradually storing the applied level into the individual cells. The short connecting fibers between neighbor-

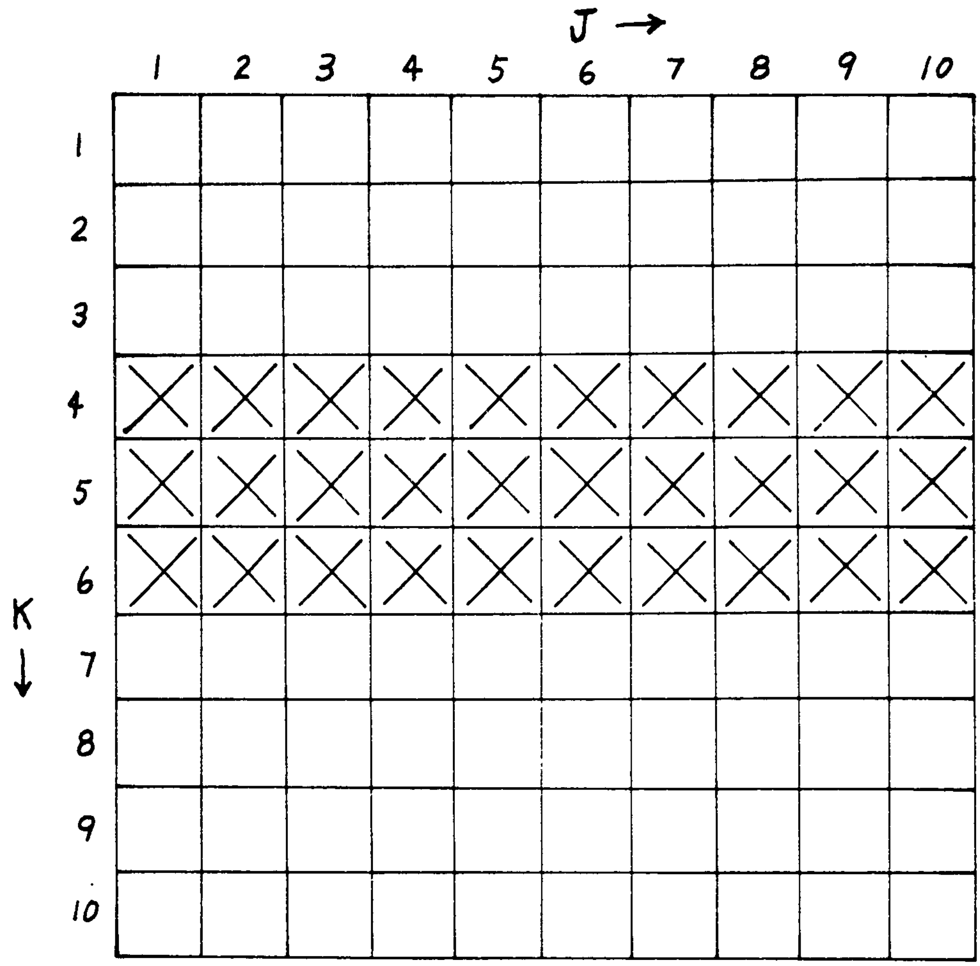


Fig. 4

Model of Area 17

ing neurons in area 17 were simulated by coupling each of the cells in the 10x10 array with its four adacent cells. Thus, a portion of the input to a certain cell would be fed to each of its four adjacent cells. This was the simulation of area 17 attempted here. The sub-cortical interconnecting fibers between cells within area 17 and from area 17 to areas 18 and 19 have not been considered, although these are probably responsible for the most sophisticated aspects of visual data processing. It was decided to test this partial simulation of area 17 for its pattern invariance recognition capabilities before attempting further simulation of the visual system.

In Fig. 5 is shown a flow diagram of the digital computer simulation of the 10x10 array of supercells. The input, P(K,J), is the 10x10 array of signal levels representing a black and white pattern. The bar pattern in Fig. 4 will be taken as this input and the level applied to the cell in position (5,5) will be followed through the flow diagram. This level for P(5,5) is 50 units (these units are arbitrary and represent the physiological situation where light intensity is coded into pulse firing rate in nerve cells.), which is the primary input to the summer block. Also, there are four inputs to this block from the four cells adjacent to cell (5,5). As shown in Fig. 5, these are P(4,5), P(5,6), P(6,5), and P(5,4). The blocks G1, G2, G3, and G4 are multipliers which may be varied to change the degree of input coupling between

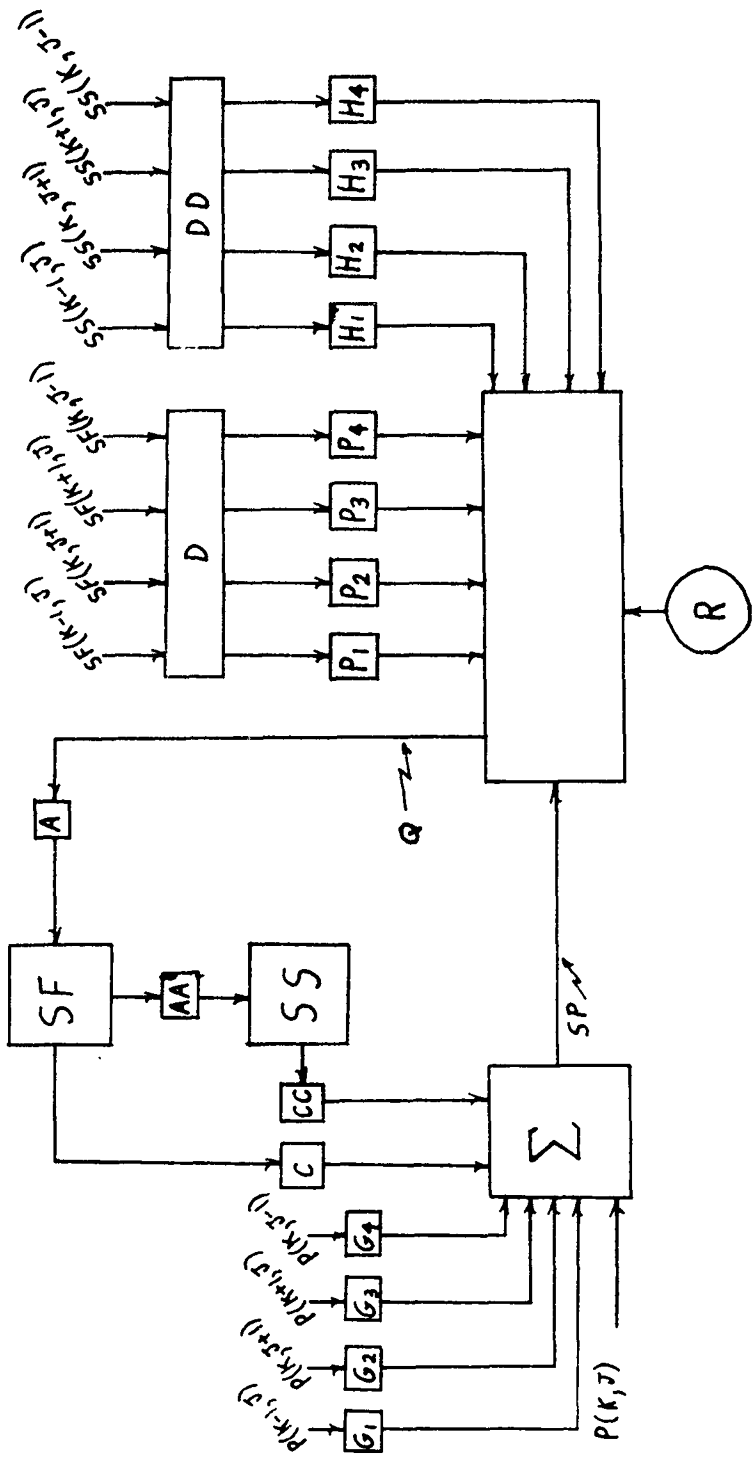


FIG. 5

FLOW DIAGRAM FOR THE COMPUTER SIMULATION OF MODEL PR-9 adjacent cells. If these multipliers are assigned a value of 0.1, then in this pattern the coupled input to cell (5,5) from each of these adjacent cells would be five units. Thus, initially the total input to the summer block is 50 + 20 = 70 units (assuming the feedback through blocks C and CC is zero). The output of the summer block, SP, is 70 units, which is fed into the next block. The input R to this block is a reference signal, which will be considered as zero. The other eight inputs to this block will also be considered as zero initislly.

The output of this block is called the error signal and is designated as Q. This error is defined as

$$\begin{aligned} Q = R - SP &- E[H_1 \cdot DD \cdot SS(K-1,J) + P_1 \cdot D \cdot SF(K-1,J)] \\ &- F[H_2 \cdot DD \cdot SS(K,J+1) + P_2 \cdot D \cdot SF(K,J+1)] \\ &- G[H_3 \cdot DD \cdot SS(K+1,J) + P_3 \cdot D \cdot SF(K+1,J)] \\ &- H[H_4 \cdot DD \cdot SS(K,J-1) + P_4 \cdot D \cdot SF(K,J-1)] \end{aligned}$$

Thus, Q, initially, is -70 units. The block A is a multiplier which may be varied to control the feedback amplitude. If A = 0.1, then the output of block A is (-70) (0.1) = -7 units. Block SF is a 10x10 array in which the feedback signal is stored. The signal of -7 units is stored in position (5,5) of this array. From block SF there are two outputs, one through the multiplier block C to the input summer, and the other through the multiplier AA to block SS. Block SS is a 10x10 array in which is stored a portion of the signal from the SF array. A typical value used for AA is 0.01, thus -0.07 units is initially stored in position (5,5) of the SS array. From the SS block, the -0.07 units flows through a multiplier CC and enters the input summer block. If C and CC are set at 1.0, then signals of -7 units and -0.07 units from the SF and SS arrays are fed back into the input summer block. This process of storing a negative portion of the input voltage to each cell in the SF and SS arrays is carried out for each cell in the 10x10 array to complete the first iteration.

In the second iteration, the input from P(5,5) and the four adjacent cells still totals 70 units, but now the negative feedback signals are added to this, producing a value of 62.93 units for SP. This is fed into the second block along with the reference signal R, which remains constant at zero. Now the other eight inputs to this block are no longer zero. These inputs represent coupling of the stored signals between adjacent cells. The amount of this coupling is controlled by setting the multipliers D and DD equal to 0.1. The multipliers P1, P2, P3, P4, H1, H2, H3, and H4 are set equal to 1.0. In this second iteration, the coupled signal from each adjacent cell in the SF storage array will be -0.7 units, and the signal from each adjacent cell in the SS storage array will be -0.007 units. Thus, the value of Q in the second iteration will be -60. 0102 units. From the multiplier A, the feedback of -6.0102 units will be stored in position (5,5) in the SF array. This -6.0102 units, added to the -7 units stored during the first iteration, produces -13.0102 units as the feedback through C to the input summer for the third iteration. Similarly, the feedback from SS for the third iteration will be -0.130102 units.

It can be seen that the negative of the input pattern is slowly being stored in the SF array, and even more slowly stored in the SS array. Also, the error signal Q is slowly being reduced. This reduction of the error signal to a small value is used as an indication that the negative of the input pattern is well stored in the SF array. After the negative of the input pattern is well stored, at any later time when the same pattern is used as an input, the error signal Q will be very small on the first iteration. This will indicate recognition of the pattern. If a different pattern is used as the input, the value of Q will be larger on the first iteration. The magnitude of Q will be an indication of the degree of non-recognition of the pattern.

The flow diagram described above was programmed for the IBM 1620 digital computer. The program, which was written in Fortran language (slightly modified for use at the Air Force Institute of Technology), is shown on pages 78 through 80 in Appendix A. This program was designed to permit the operator to control the degree of coupling between adjacent cells for both the input signals and the storage array signals. The rate of storage may also be varied by changing the multiplier constants A and AA. The amount of feedback may be changed by assigning various values to the constants C and CC. The capability of obtaining a print out and punch out of the SF, SS, and DE arrays after each iteration was included in the program. The DE(K,J) array is a 10x10 array of the error signal Q.

An explanation of the computer program will now be made. This may be followed by referring to the program in Appendix A. The first statement gives the dimensions of the input array, P(K,J), the fast storage array, SF(K,J), and the error signal array, DE(K,J). The next four READ statements set the amount of coupling between cells for the input and storage of the input pattern. The following PAUSE permits loading the cards for the input, P(K,J), into the reader hopper. In the DO1 loop, the input pattern is read into the computer. The PAUSE following statement 1 permits loading the cards for the fast storage array, SF(K,J), into the reader hopper. The DO 2 loop then reads this array into the computer. The PAUSE following statement 2 and the DO 3 loop permit loading and reading of the slow storage array, SS(K,J), into the computer . Statement 31 contains the format for the input of these three arrays.

The ITNO statement sets the first iteration number equal to zero. B is the symbol for a positive value of the error signal Q. Statement 52 sets B equal to zero for the initial iteration. The letter U is the symbol for the sum of the absolute values of all the error signals, Q, in the DE(K,J) array. The statement following statement 52 sets U equal to zero for the initial iteration. The letters UU are the symbol for the sum of the squares of the error signals in the DE array. This is initially set equal to zero. The letters UUU are the symbol for the algebraic sum of the error signals in the DE array. This is also set equal to zero for the initial iteration. The DO 4 loop is the basic iteration of the program. This loop computes the error signal, Q, for each cell in the 10 x 10 array from K=1 to K=N and from J=1 to J=N. The value of N is set in statement 34 at 10, which is the largest value of K and J in the array. The computed value of Q for each cell is then stored in the proper position in the DE(K,J) array, and at the completion of the DO 4 loop the DE array will contain a value of Q for each of the 100 cells.

Statements 5 through 17 ensure that zero coupling is made to cells on the perimeter of the array from positions outside the array. Statement 18 and the five following statements set the value of Q for each cell equal to the reference signal, R, minus the total pattern input, SP, minus the coupled storage signals from the four adjacent cells. The next statement, DE(K,J) = Q, then stores the computed value of Q into the proper position in the DE array. The statements from the IF(E*F*G*H) 69,4,69 statement through statement 4 perform the various summations of the errors in the DE(K,J) array to obtain values for U, UU, and UUU. The value of BB, which is the largest error signal in the DE array, is also obtained in these statements. The location of this largest error in the DE array is also obtained and designated by L and M, which correspond to the K and J coordinates of the array.

Following statement 4 a print out is made of the iteration number, ITNO, the value of the largest error signal, BB, the coordinates of this error signal, L and M, the sum of the absolute values of the error signals, U, the sum of the squares of the error signals, UU, and the algebraic sum of the error signals, UUU. Statements 100 and 101 give the format for the print out of these error signals. The statement following statement 101 increases the iteration number by one integer. The following two IF statements provide external control of the program at this point. If switch 3 is on, the computer will go to statement 43, pause, then proceed to statement 34. This permits an exit from the series of iterations with the present data and permits new data to be read into the program and a new series of iterations to begin. If switch 3 is off, the computer will go to statement 53, where if switch 1 is on, a print out of the SF array will be made. If switch 1 is off, statement 50 will be executed. This is the entry into the DO 51 loop, which stores a portion of the DE error array in the SF array and then stores a portion of the SF array into the SS array. The computer will now go to statement 52 and execute a new iteration. If switch 1 is on, the SF array will be printed (statements 40 through 1001). Then, if switch 2 is on, a punch of the printed SF array will be executed (statements 25 through 30). If switch 2 is off, no punch will be made and the computer will print the SS array next (statements 26 through 141). Again, if switch 2 is on, a punch of the printed SS array will be executed (statements 29 through 152). Next a print of the DE array will be made (statements 153 through 142). This completes the printing and/or punching of the storage and error arrays and the computer will go to statement 50 and perform the DO 51 loop (storing the error array in the storage arrays), then go to statement 52 and begin a new iteration.

The three external control switches provide several options on the output of the computer. With all three switches off, the only output will be the printing of ITNO, B, L, M, U, UU, and UUU at the end of each iteration. This permits the operator to monitor the error signals and determine when the negative of the input pattern has been suitably stored in the storage arrays. With only switch 1 on, this same information will be printed and also the SF, SS, and DE arrays will be printed after each iteration. With switches 1 and 2 on, all the previous information will be printed, and a punch of the SF and SS arrays will be made after each iteration. Therefore, switch 2 will be turned on when it is determined that a pattern has been suitably stored, and a punch of this stored pattern will be made and filed for future use. If switch 3 is turned on, the computer will leave the basic iteration and await new input data. This provides an exit from the program in case the printed output data are uninteresting or incorrect and it is desired to begin storage or comparison of a different pattern.

In this chapter the Model PR-9, patterned after the human visual system, was derived, a flow diagram for the computer simulation was described, and the Fortran program for the computer simulation was explained. The next step in this investigation will be to derive various patterns, store them in the model, and then test the model for recognition of these patterns after they have undergone variations. This step is discussed in the next chapter.

V. Testing Procedures

After the model of area 17 was developed and a computer program completed, it was necessary to derive several sets of patterns to use in testing the pattern invariance recognition capabilities of the model. It was decided to begin with a very simple bar pattern and proceed to more complex patterns.

The first pattern set is shown in Figs. 6, 7, and 8. An X in the pattern represents a signal of 50 units and a blank indicates a signal of zero units. The basic procedure followed was to store pattern # 1-A in the SF and SS arrays until the sum of the squares of the error signals, UU, approached a minimum, then obtain a punched output of the SF and SS arrays. These punched arrays of pattern # 1-A were now read back into the storage arrays, with pattern # 2-A used as the input pattern. The computer was now run through several iterations and the typed output of UU used as an indication of the degree of recognition of pattern # 2-A. This comparison procedure was repeated for each of the remaining patterns in set "A". The data obtained from these runs are on pages 83-92 in Appendix C.

The coupling constants G, H, and P permit varying the coupling between cells in the horizontal or vertical direction. The constants D and DD permit varying the overall coupling from the SF and SS arrays respectively.

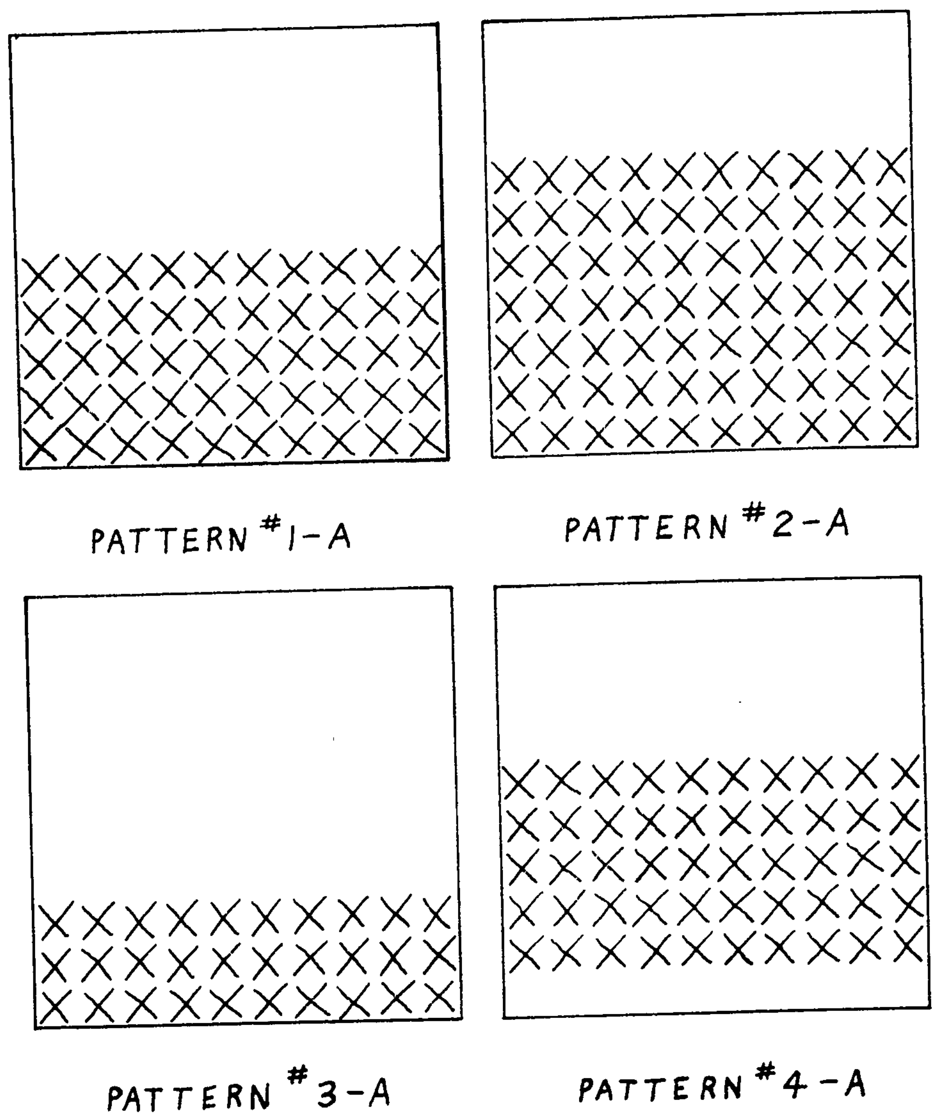


FIG. 6
PATTERN SET "A". THE NINE PATTERNS IN THIS SET ARE SHOWN IN THIS FIGURE AND THE TWO FOLLOWING FIGURES.

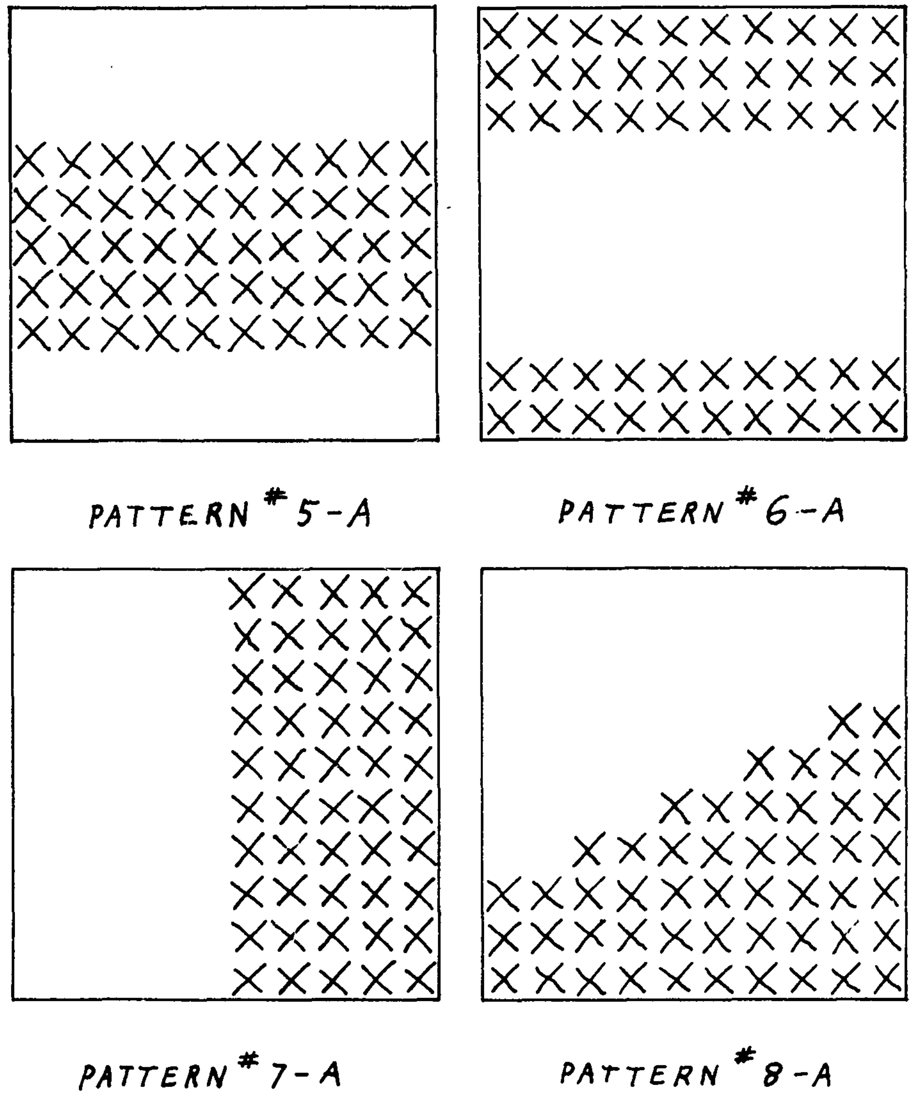
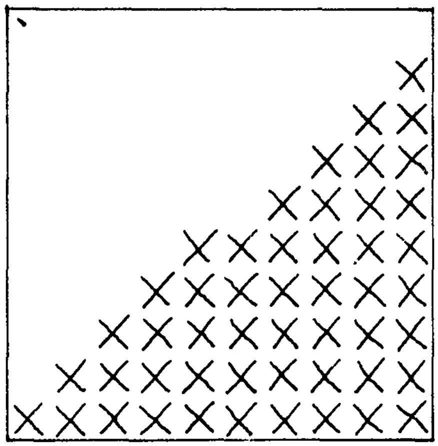


FIG. 7

PATTERN SET "A"



PATTERN # 9-A

FIG. 8

PATTERN SET "A"

The constants A, AA, C, and CC permit varying the rate of storage of the pattern. For all of the testing procedures, the values of C and CC were set at 1.0, A was set at 0.1, and AA was set at 0.01. This permitted a moderate rate of storage in the SF array and a considerably slower rate of storage in the SS array. In the testing with pattern set "A", various types of coupling were used to determine their effects upon the storing of pattern #1-A and upon the recognition of the following patterns in the set.

The four input statements which set the values of the constants determining coupling and rate of storage are called the "metric". The five metrics used in testing the coupling effects are shown in Appendix B. Metric #1 provides equal coupling from each of the four adjacent cells by setting the G, H, and P constants equal to 0.25, and D and DD equal to 1.0. Metric #2 provides stronger vertical coupling than horizontal by setting G1, G3, H1, H3, P1, and P3 equal to 0.5. Metric #3 provides for stronger horizontal than vertical coupling by setting G2, G4, H2, H4, P2, and P4 equal to 0.5. Metric #4 provides no coupling between adjacent cells by setting D, DD, and the G, H, and P constants equal to zero. Metric #5 provides equal coupling, but doubles the coupling over that provided by metric #1 by setting the G, H, and P constants equal to 0.5.

Pattern #1-A was stored using metric #1, metric #2, and metric #3. Fifteen iterations were required to store the pattern with metric #1 before the value of UU reached a minimum (data on pages 83-84 in Appendix C). Thirteen iterations were required with metric #2, and twelve iterations with metric #3. Thus, somewhat faster storage was obtained by using stronger vertical or horizontal coupling than equal coupling. A punched output of the stored patterns was obtained for each of these three metrics. Each of these three stored SF and SS arrays of pattern #1-A were then compared with pattern #2-A to determine if the type of coupling used in the storing procedure affected the recognition capability. As shown in the data on pages 88-90 in Appendix C, the metric used in storing pattern #1-A had little effect upon the recognition of pattern #2-A. The values of UU on the initial iteration of the comparison were 123121; 121797; and 123477. On the basis of these results, it was decided to use metric #1 in the future storing of patterns.

The next step was to make a comparison of all the patterns in set "A" with the stored pattern #1-A to determine the degree of recognition of these patterns. This comparison was made by setting the SF array equal to zero and feeding the stored SF array of pattern #1-A into the SS array. This would represent a thoroughly stored pattern #1-A. In 15 iterations the pattern had been well stored in the SF array, while the SS array had barely begun to store the pattern. After a great many more iterations the pattern would filter through the SF array and eventually become thoroughly stored in the SS array, leaving the SF array at zero. This lengthy process was simulated by feeding the stored SF array of pattern #1-A into the SS array for the comparison procedure. This stored pattern #1-A was then compared with pattern #1-A as the input pattern and the value of UU on the first iteration taken as the value representing complete recognition of the input pattern. All the remaining patterns in set "A" were then compared with the stored pattern #1-A and the value of UU obtained on the first iteration used as a measure of the degree of recognition of the pattern.

Pattern set "B" was then tested on the model. The patterns in this set are shown in Figs. 9 through 13. Pattern #1-B was used as the standard pattern. It was stored in 16 iterations with metric #1. To simulate thorough storage, the stored SF array of pattern #1-B was used as the SS array during the comparison of each of the patterns in set "B" with the standard pattern #1-B. The SF array was set equal to zero. Metric #1 was used in the comparison procedures. Four iterations were completed in the comparison of each pattern in set "B" with pattern #1-B. These patterns were designed to simulate vertical displacement and rotation of the bar in pattern #1-B. The value of UU was used as an indication

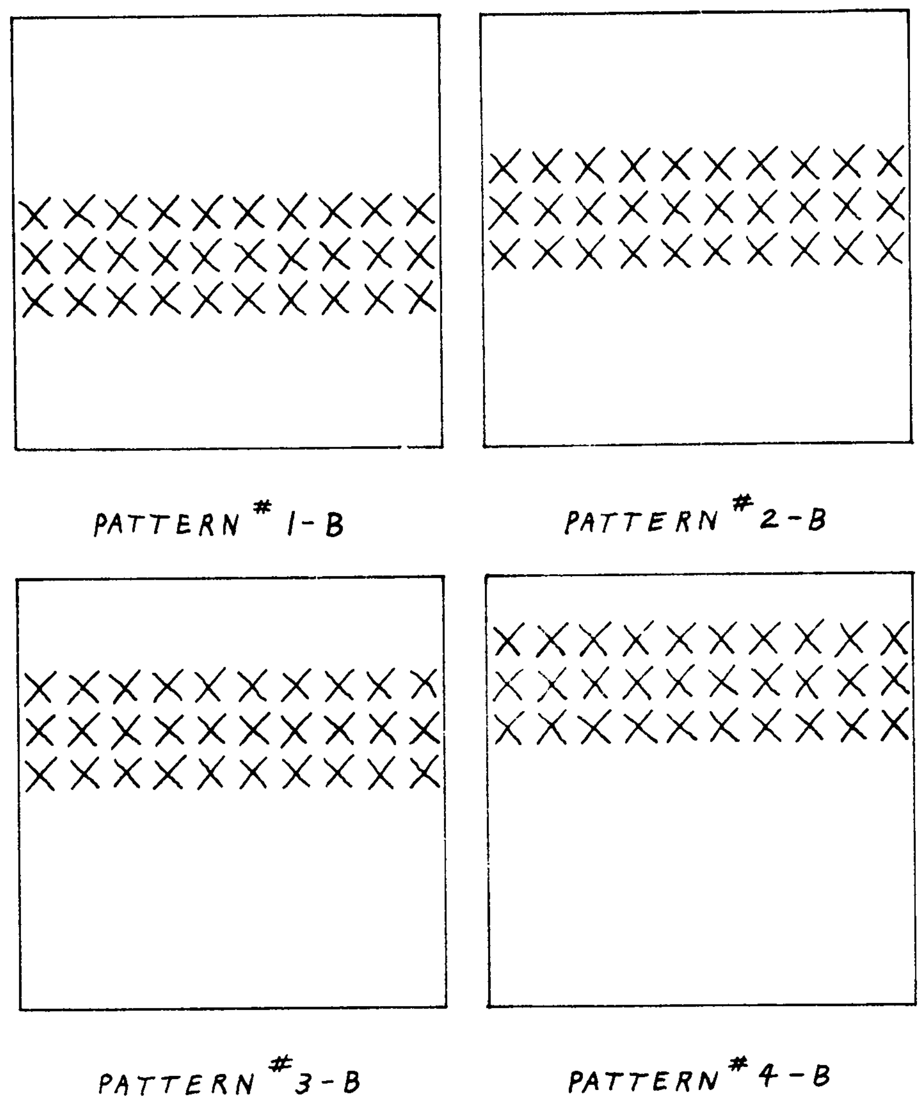


FIG. 9
PATTERN SET "B". THE 20 PATTERNS IN THIS SET ARE SHOWN IN THIS FIGURE AND THE FOUR FOLLOWING FIGURES.

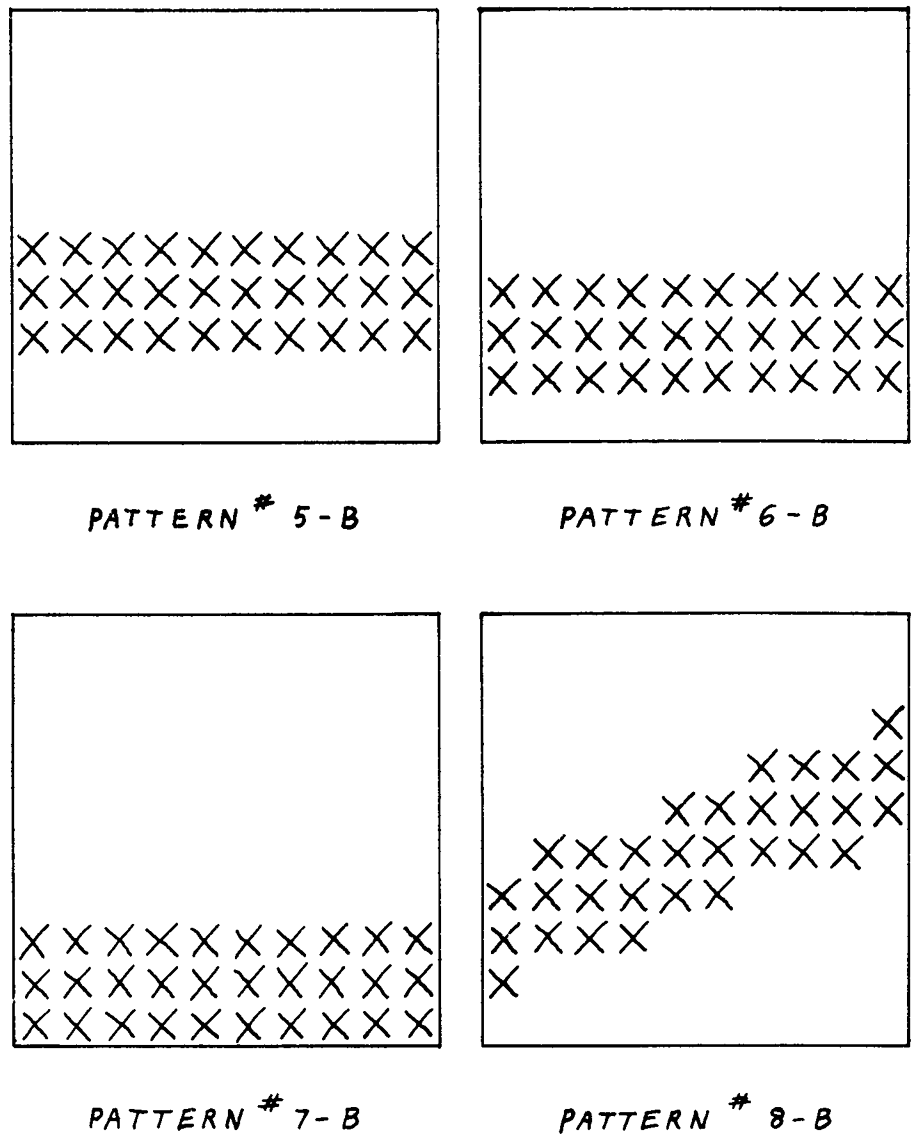
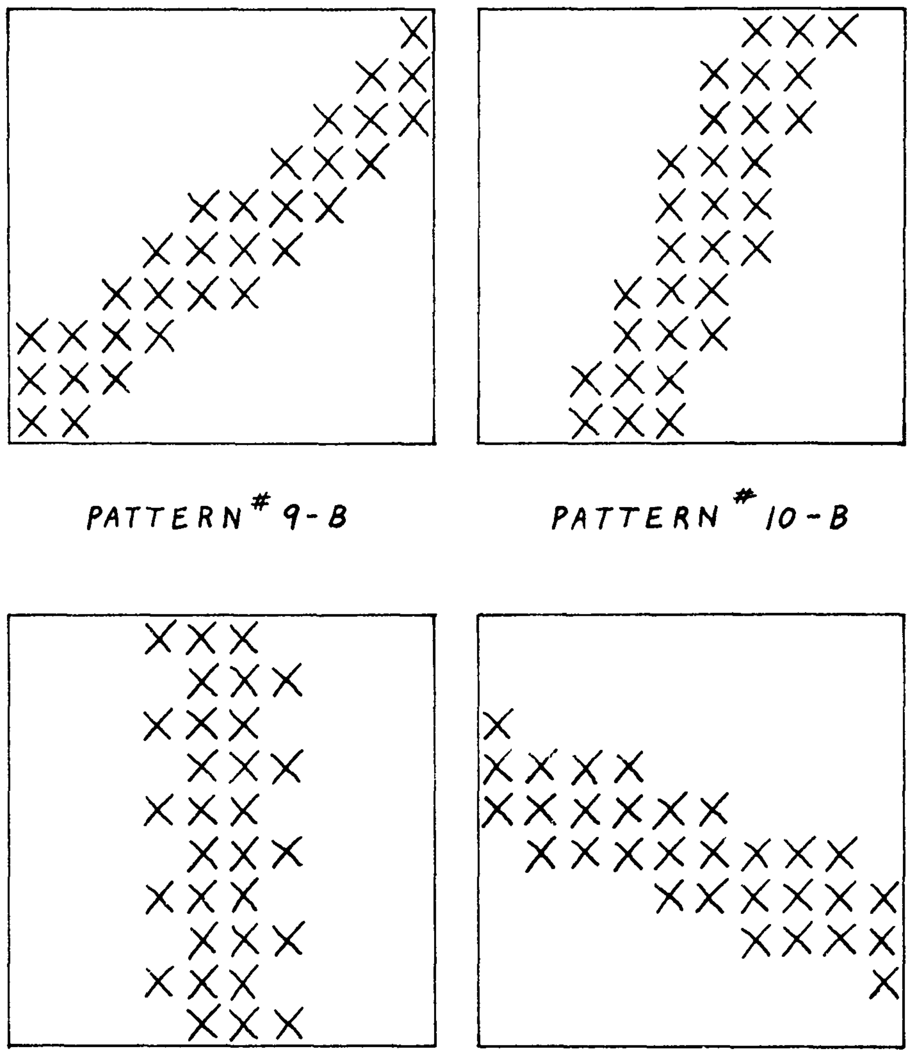


FIG. 10

PATTERN SET "B"



PATTERN # 9-B

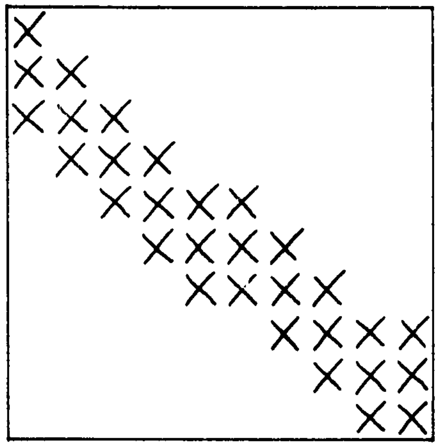
PATTERN # 10-B

PATTERN # 11-B

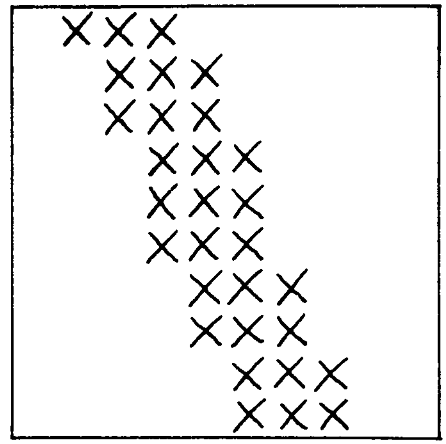
PATTERN # 12-B

FIG. 11

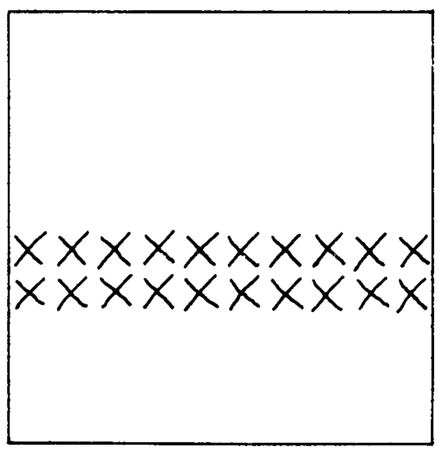
PATTERN SET "B"



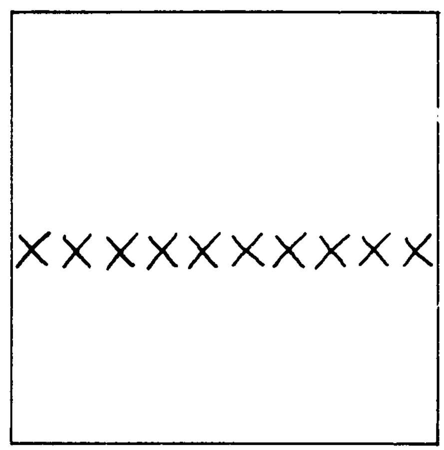
PATTERN # 13-B



PATTERN # 14-B



PATTERN # 15-B



PATTERN # 16-B

FIG. 12

PATTERN SET "B"

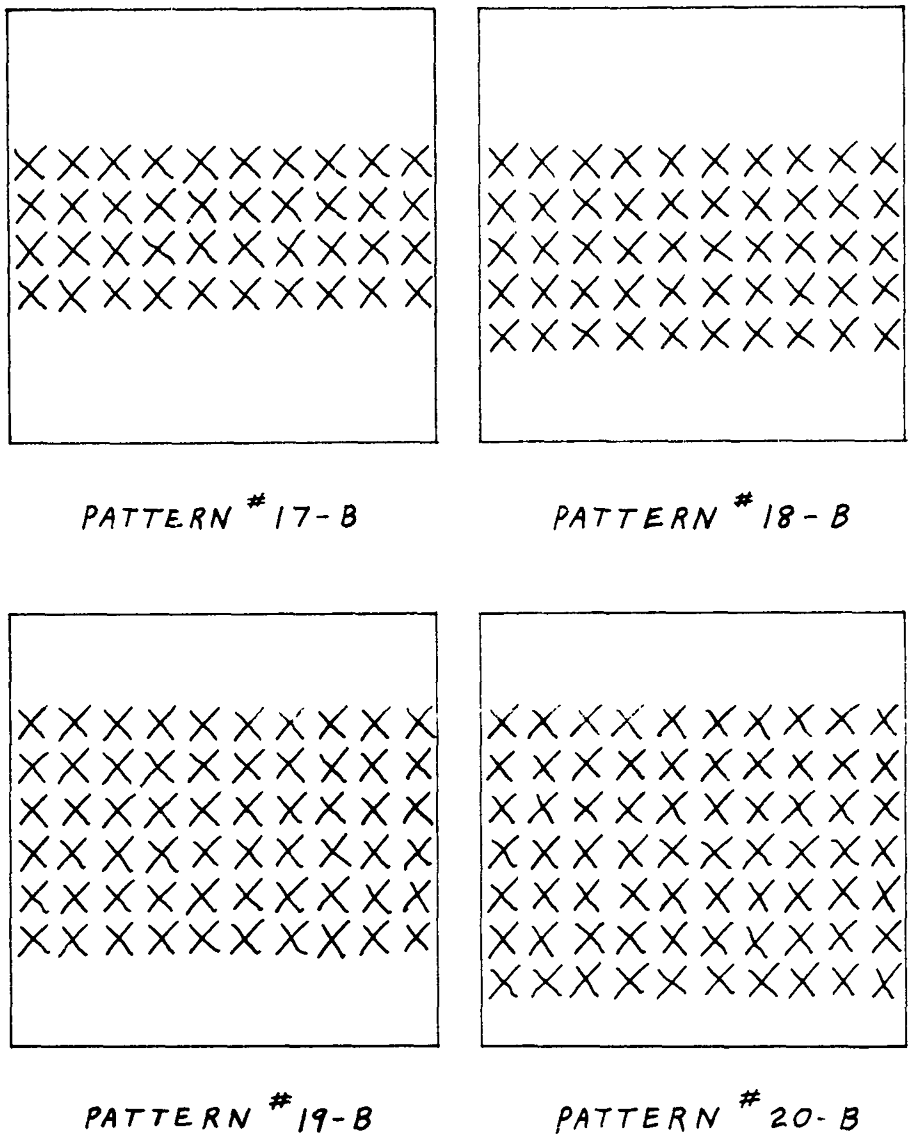


FIG. 13

PATTERN SET "B"

of the degree of recognition of the patterns.

Pattern set "C" (Figs. 14 through 19) was designed to test the model for recognition of a pattern when displaced vertically, horizontally, or diagonally, and when varied in size and shape. The metric used in the comparison of the vertically displaced patterns was varied to determine if one type of coupling provided better recognition capabilities than another. Pattern 1-C was stored in 16 iterations with metric #1. The remaining patterns were then compared through two iterations each with stored pattern #1-C using metric #1. Then patterns #2-C, #3-C, and #4-C, and #5-C were again compared with pattern #1-C using metric #2, metric #3, metric #4, and metric #5. This provided data for determining if one metric provided better pattern invariance recognition than the others.

Pattern set "D" (Figs. 20 through 24) was designed to test the model for its ability to distinguish variations of a certain stored letter from other letters of the alphabet. A standard letter "A" was stored and then compared with several variations of the letter "A" and other letters of the alphabet.

This completed the testing of the model in this paper for its pattern invariance recognition capabilities. Four sets of patterns were used in these testing procedures. The basic procedure was to store the first pattern of each set, then compare the remaining patterns with the stored

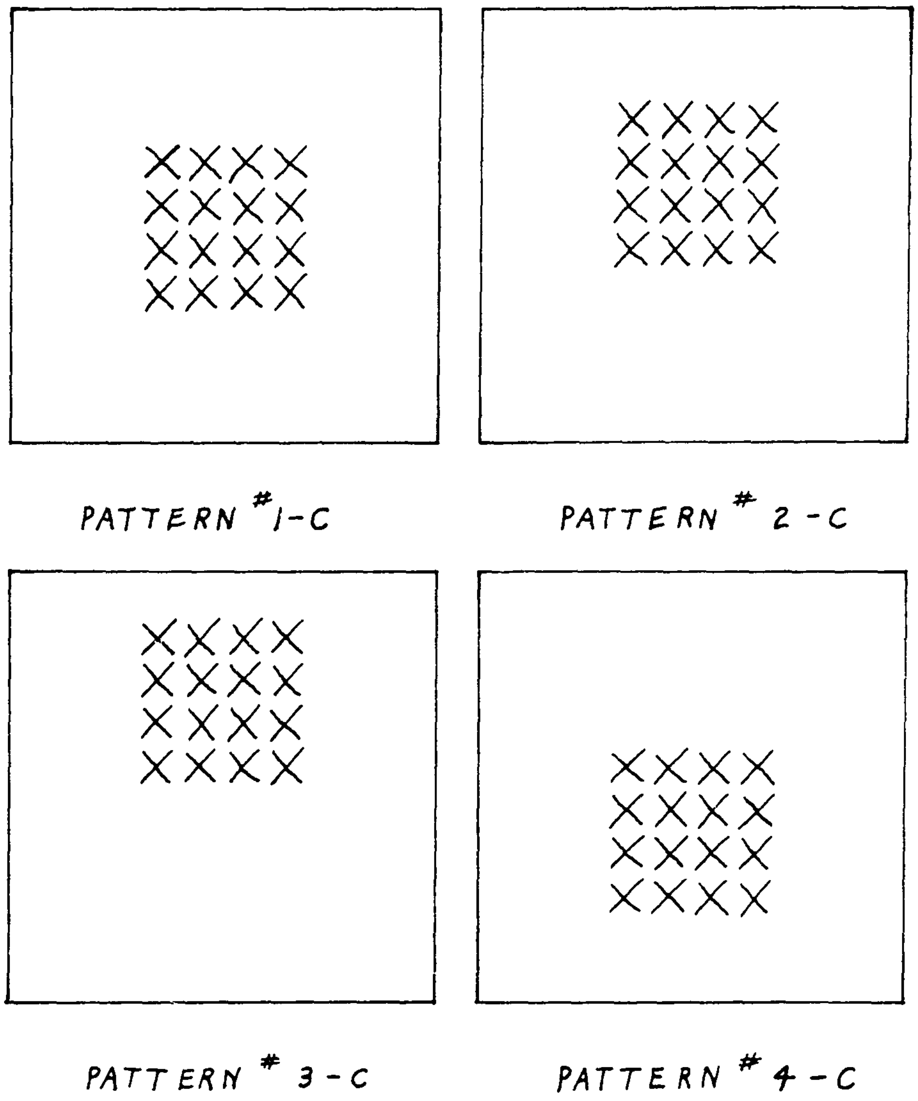


FIG. 14
PATTERN SET "C". THE 24 PATTERNS IN THIS SET ARE SHOWN IN THIS FIGURE AND THE FIVE FOLLOWING FIGURES

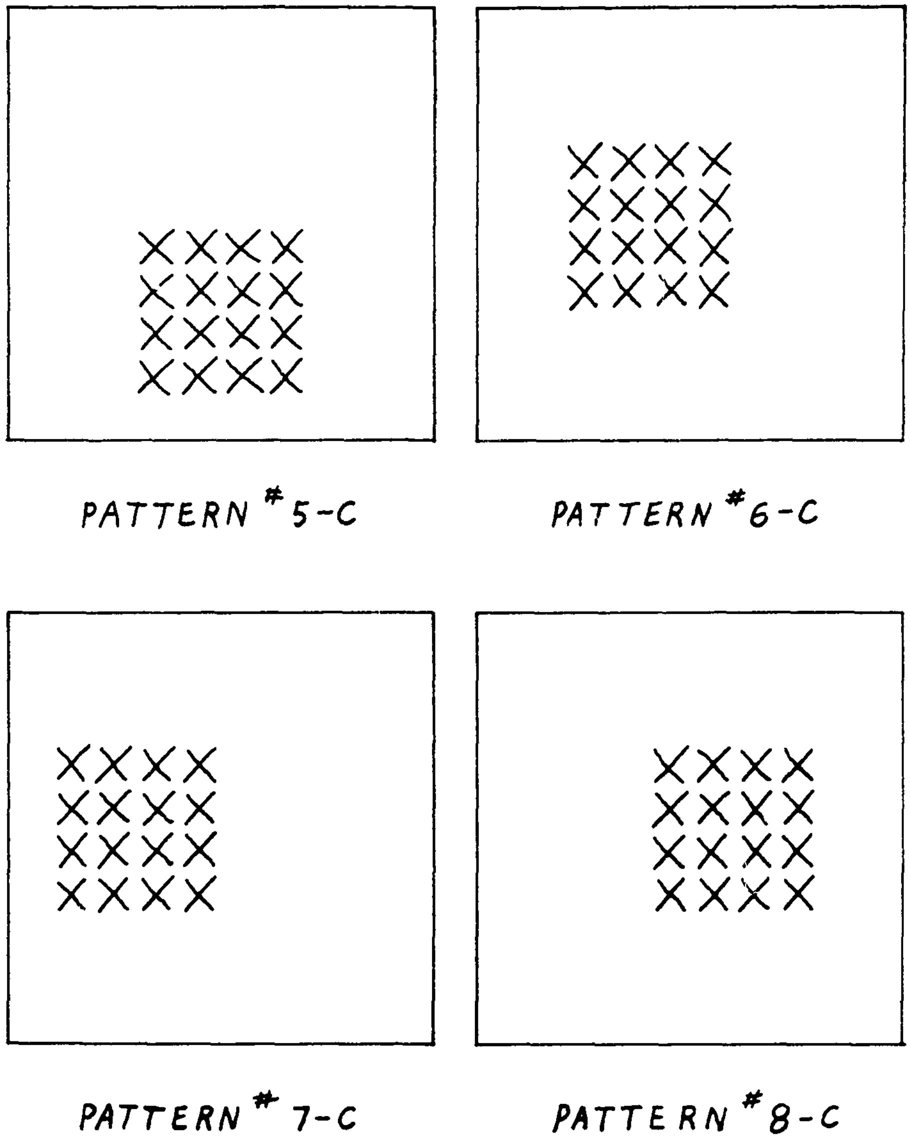


FIG. 15

PATTERN SET "C"

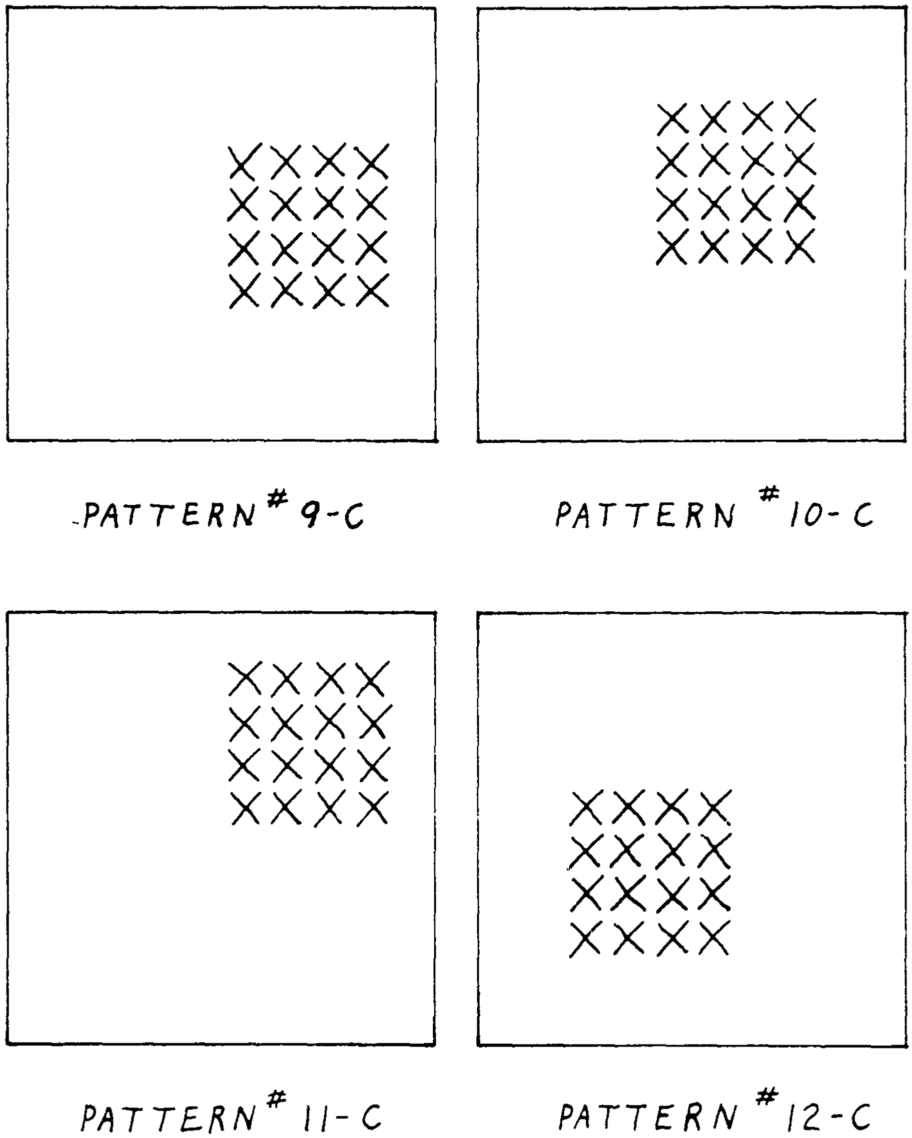


FIG. 16

PATTERN SET "C"

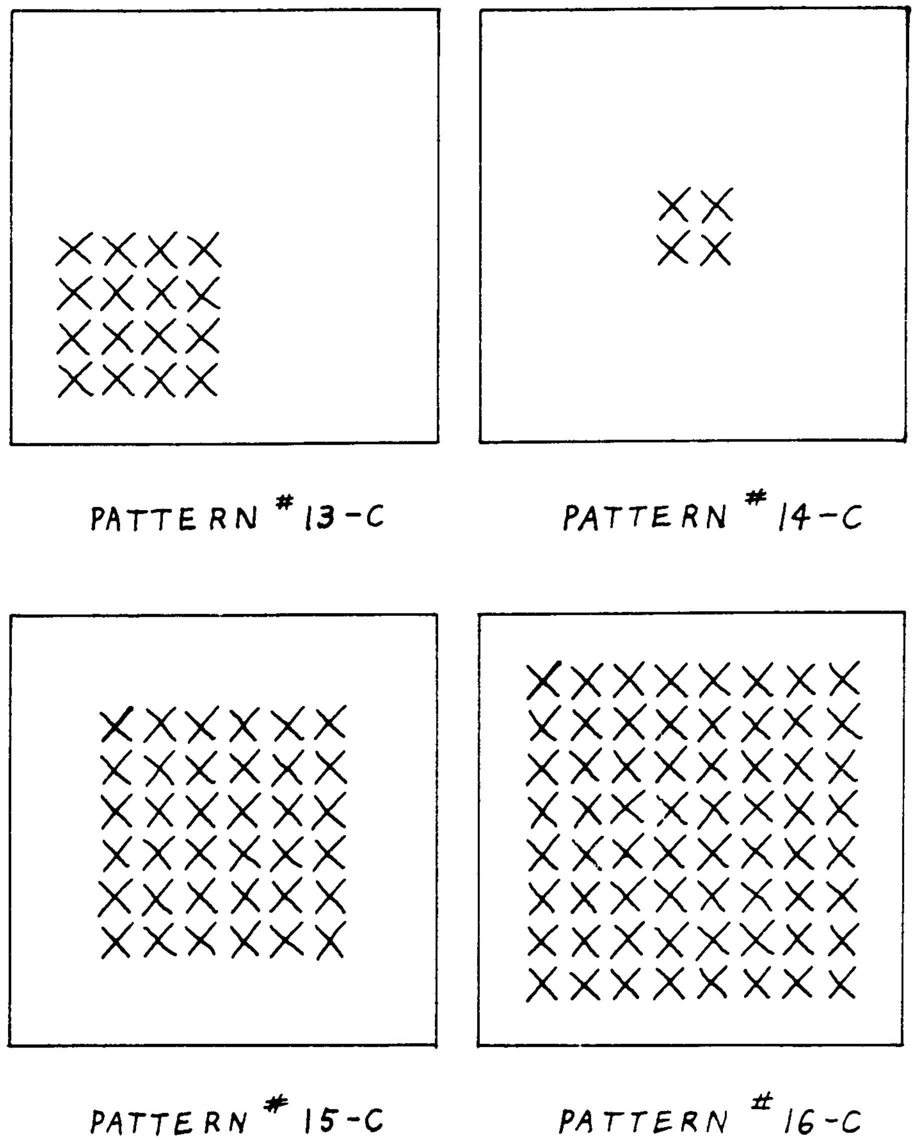


FIG. 17

PATTERN SET "C"

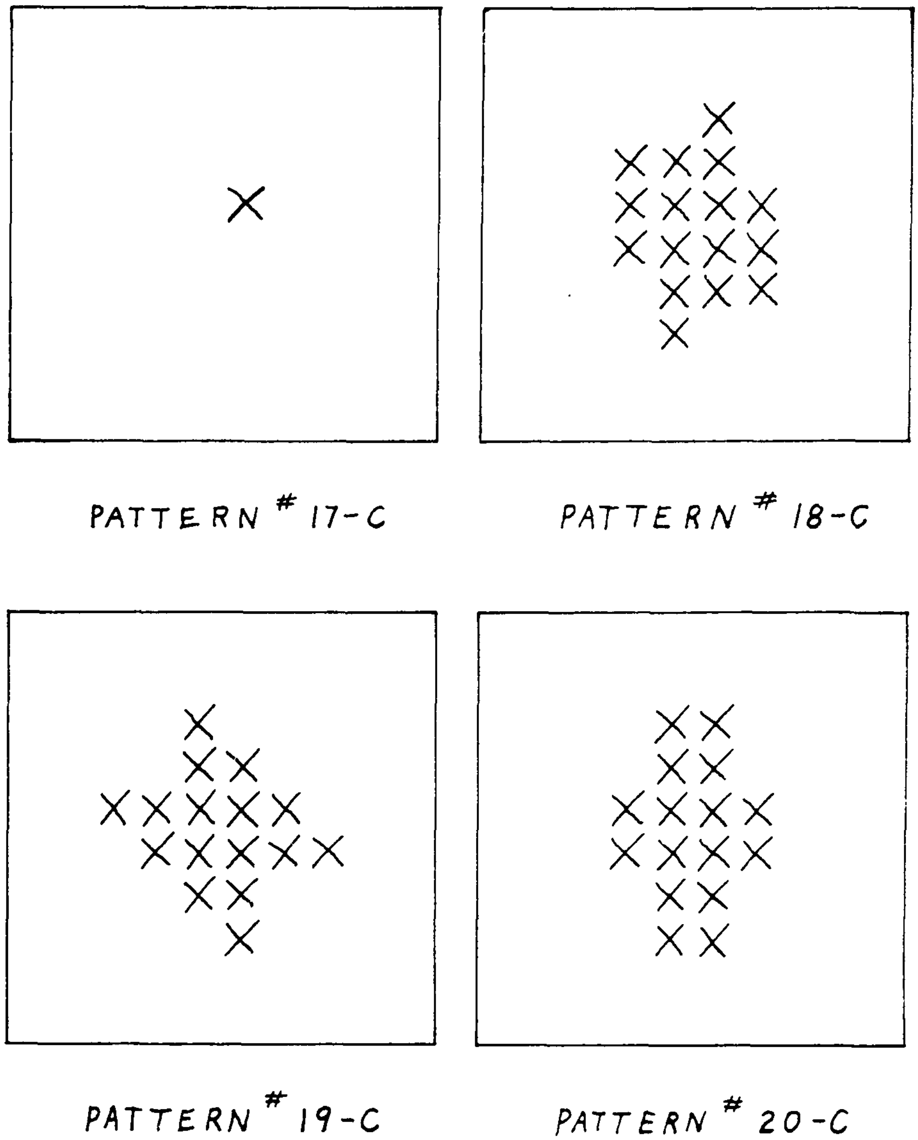
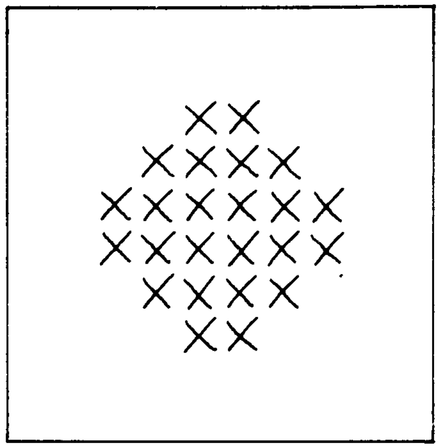
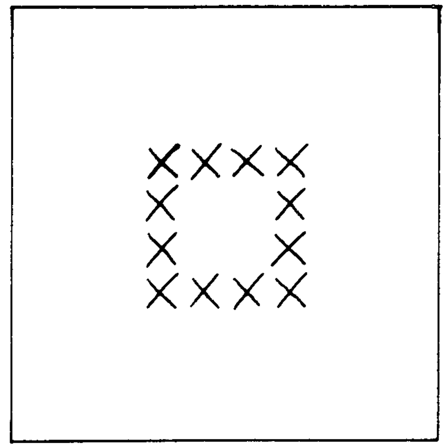


FIG. 18

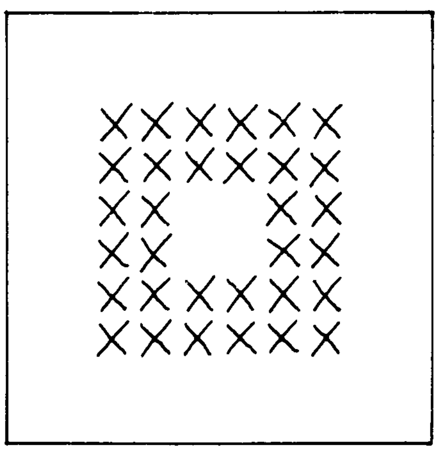
PATTERN SET "C"



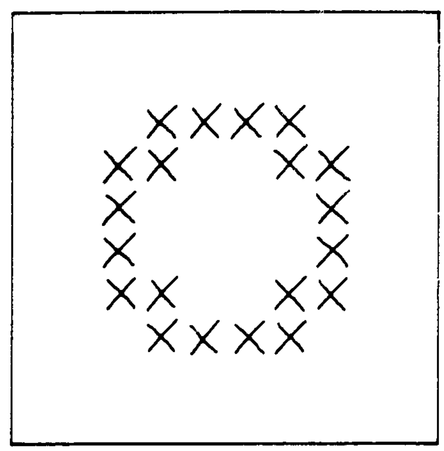
PATTERN # 21-C



PATTERN # 22-C



PATTERN # 23-C



PATTERN # 24-C

FIG. 19

PATTERN SET "C"

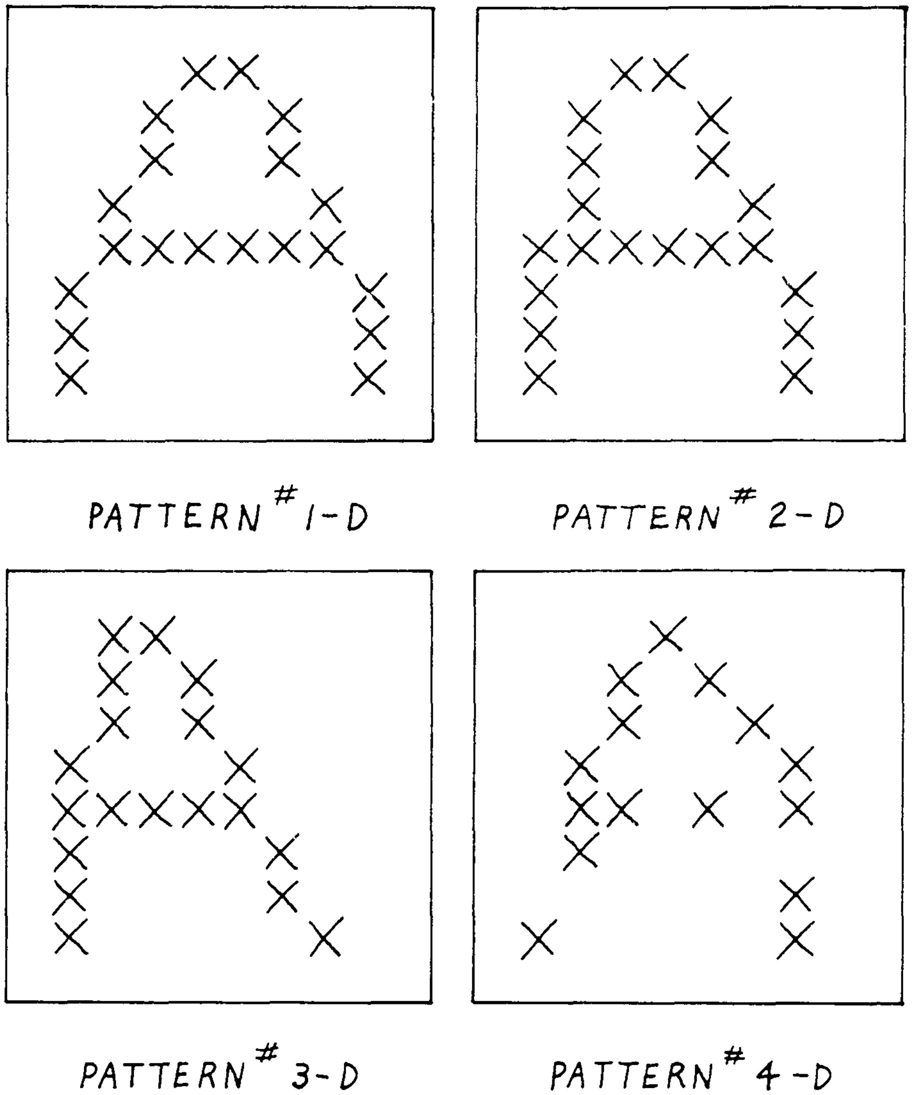


FIG. 20
PATTERN SET "D". THE 17 PATTERNS IN THIS SET ARE SHOWN IN THIS FIGURE AND THE FOUR FOLLOWING FIGURES.

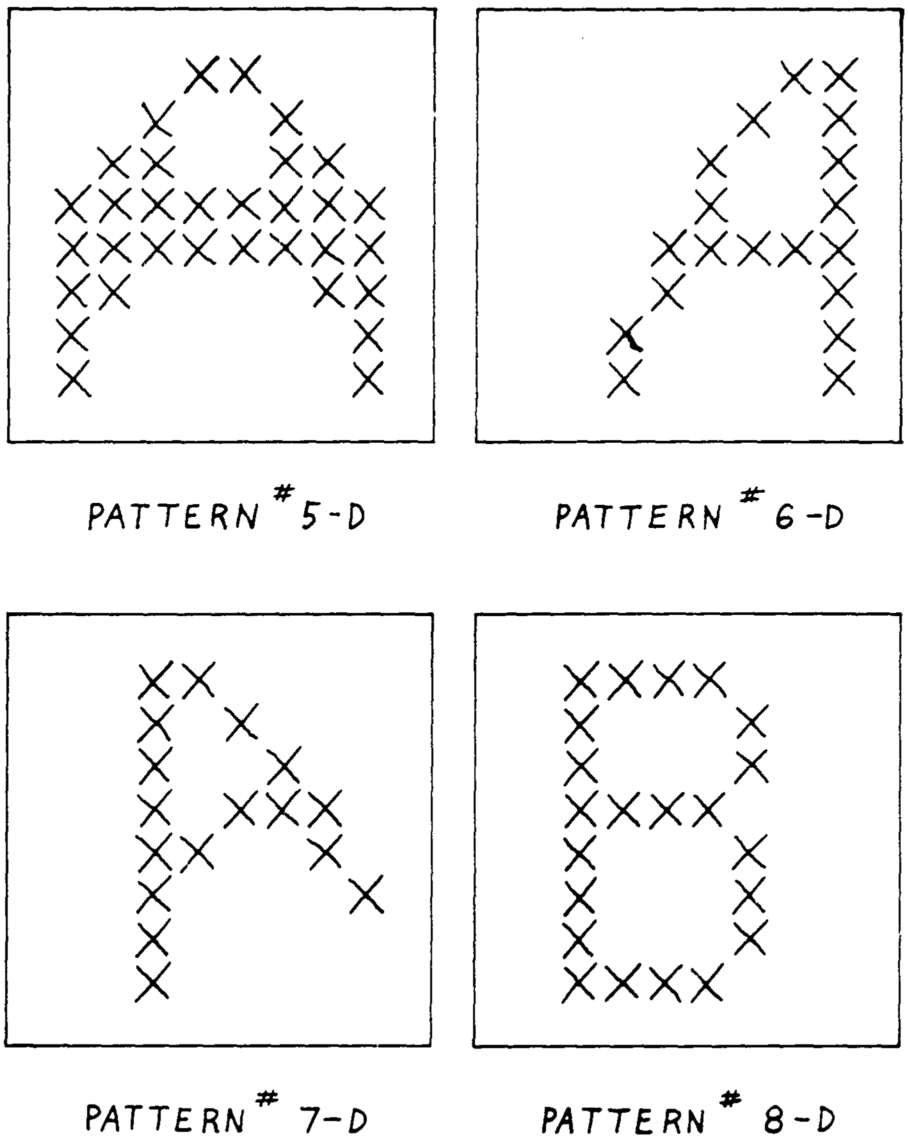
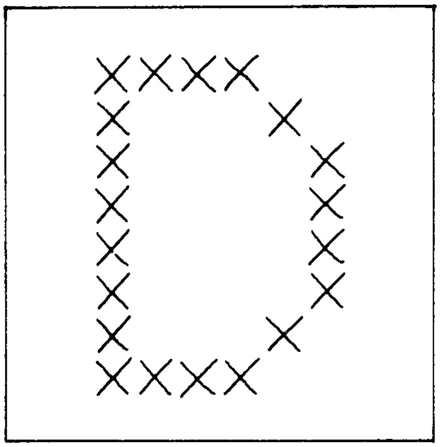
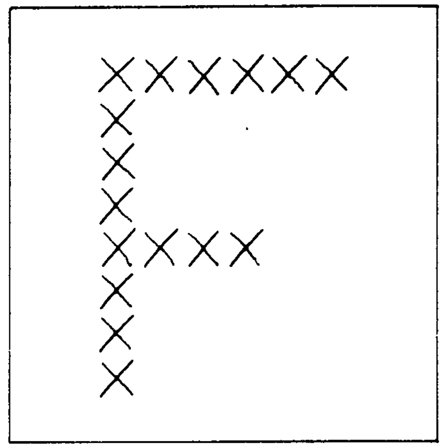


FIG. 21

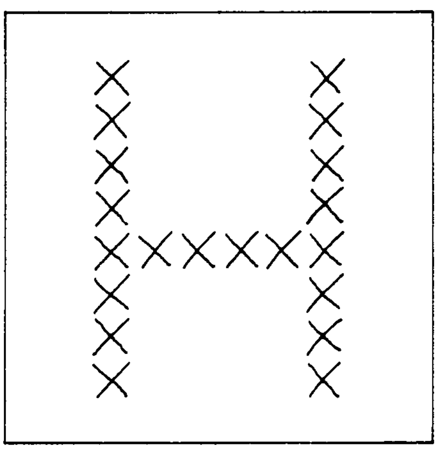
PATTERN SET "D"



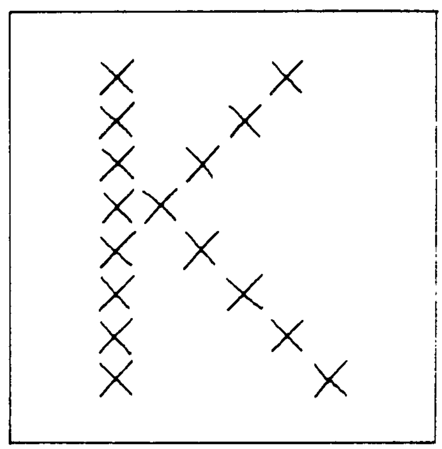
PATTERN # 9-D



PATTERN # 10-D



PATTERN # 11-D



PATTERN # 12-D

FIG. 22

PATTERN SET "D"

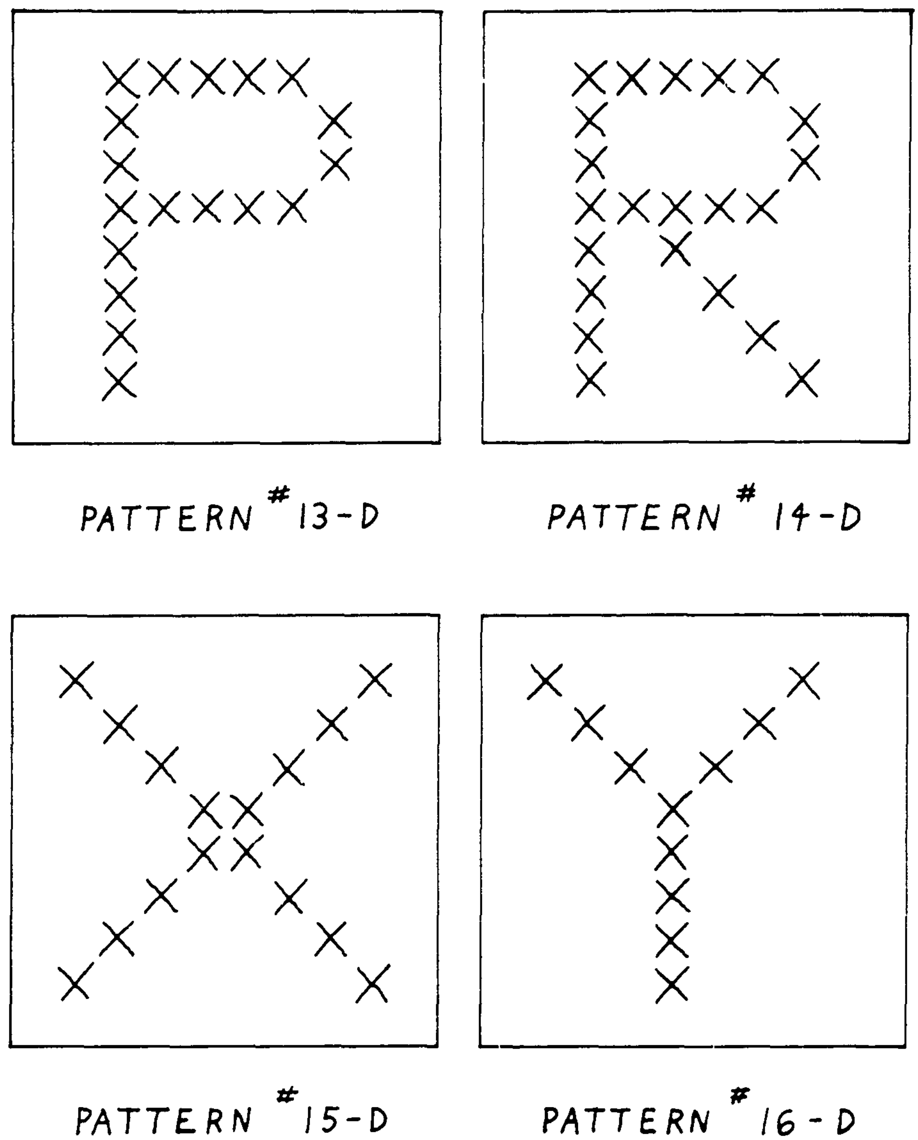
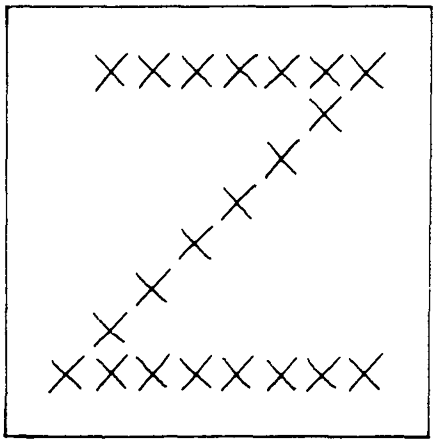


FIG. 23

PATTERN SET "D"



PATTERN # 17-D

FIG. 24

PATTERN SET "D"

pattern. The pattern sets were designed to test the model for recognition of a pattern after it was translated, rotated, or varied in size and shape. The results of these tests and the conclusions drawn from them will be discussed in the nest chapter.

VI. Results and Conclusions

The data obtained from testing model Pr-9 with pattern sets A, B, C, and D were evaluated by plotting line graphs of UU versus the amount of pattern variation. This produced graphs of the sensitivity of the model to translation, rotation, size variation, and shape variation.

Pattern #1-A is a simple horizontal bar with a width of five cells. The data obtained from testing the model with pattern set "A" (pages 90-92 of Appendix C) were used to obtain sensitivity curves for rotation and vertical displacement of this horizontal bar. These curves are shown in Fig. 25 and Fig. 26. The minimum point on these curves is the value of UU obtained by comparing the stored pattern #1-A with the same pattern as the input pattern. This point indicates complete recognition and points above this indicate a lesser degree of recognition. The lowering of the curve by sucessive iterations indicates a learning of the new patterns. For this bar pattern, a rotation of about 30 degees gave the same degree of recognition as a vertical displacement of one cell width (UU = 50,000).

The data from pattern set "B" (pages 94-99 of Appendix C) provided sensitivity curves for rotation, vertical displacement, and size variation. These curves are shown in Figs. 27, 28, and 29. Again, 30 degrees of rotation and one cell width of vertical

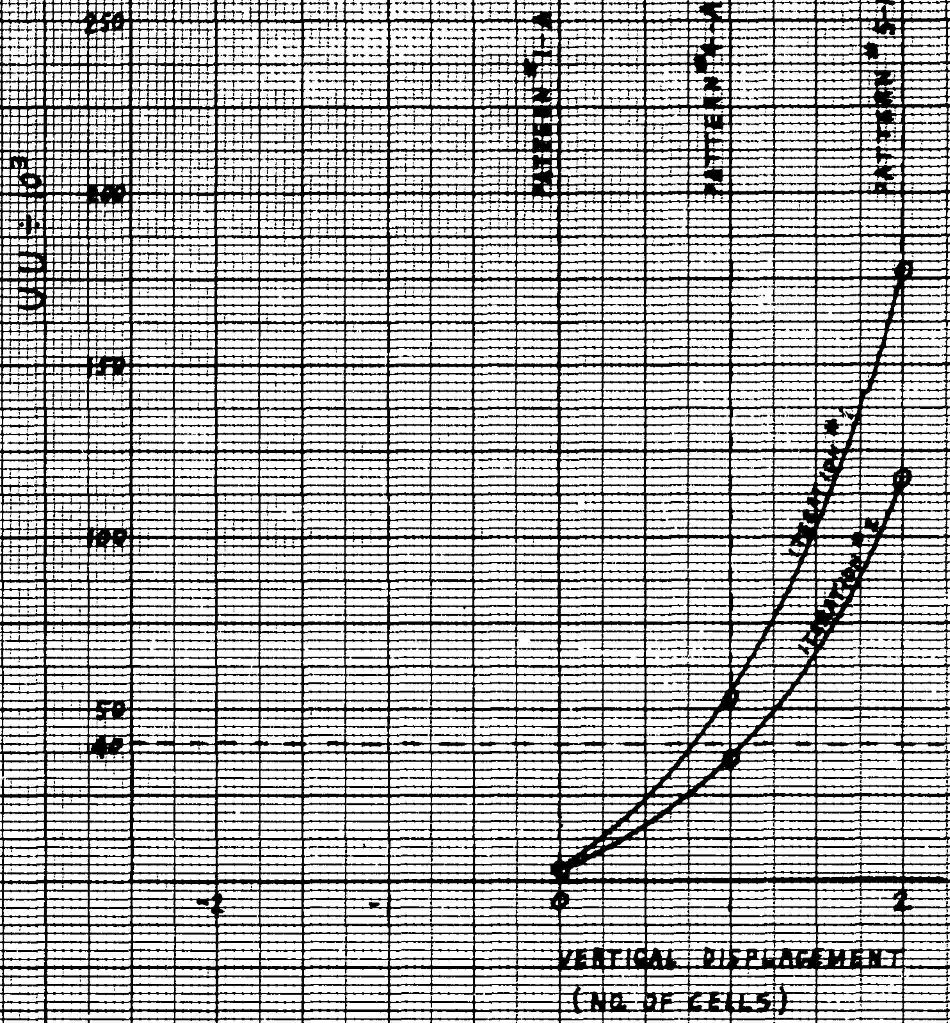


FIG. 25

SENSITIVITY OF MODEL PR-9 TO VERTICAL DISPLACEMENT OF PATTERN #1-A

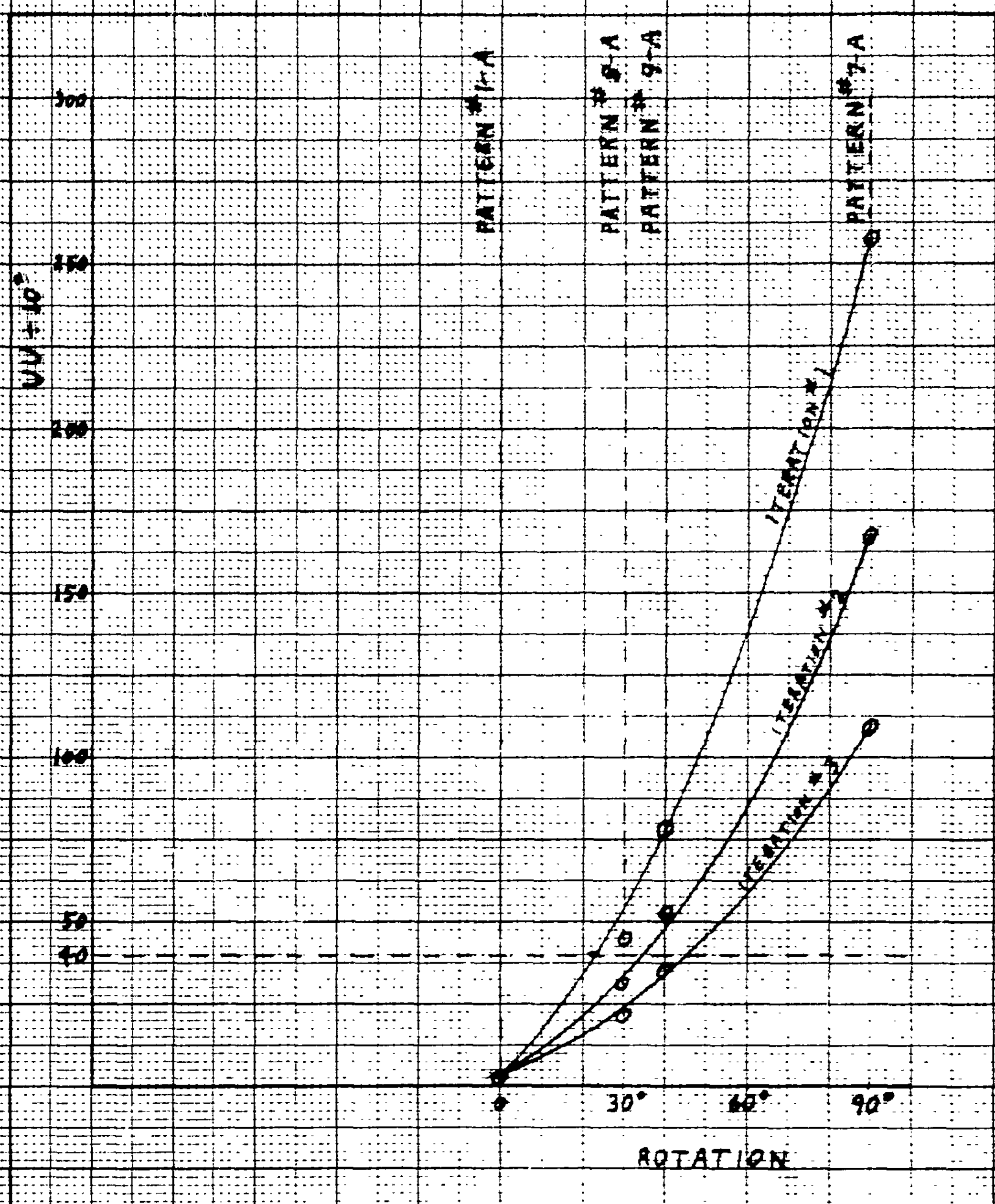


FIG. 26
SENSITIVITY OF MODEL PR-9 TO ROTATION
OF PATTERN # 1-A

displacement produced the same degree of recognition, although the value of UU was about 85,000 rather than 50,000. This indicated slightly better recognition of variations in pattern #1-A than in pattern #1-B. This could have been due to pattern #1-A being located on the edge cells at the bottom of the array. This edge cell effect also seems to produce a difference in the value of UU for the vertical displacement of pattern #1-B. When the pattern is displaced three cell widths down, it lies on the lower edge cells, producing a lower value for UU than an equal displacement in the opposite direction. The graph of sensitivity to size variation in Fig. 29 indicates a better recognition of pattern #1-B when decreased in size than when increased in size.

Pattern set "C" was designed to eliminate any edge cell effects by keeping the pattern off the perimeter of the array. The data from this set (pages 99-107 of Appendix C) provided sensitivity curves for vertical displacement, horizontal displacement, diagonal displacement, size variation, and shape variation (Figs. 30 through 34). The metric used during the pattern comparison was varied to obtain a sensitivity curve for vertical displacement for each of the five metrics (Fig. 35). The sensitivity curves for horizontal and vertical displacement were identical. The value of UU for a displacement of one cell width was 37000, which was less than the value for an equal displacement of pattern

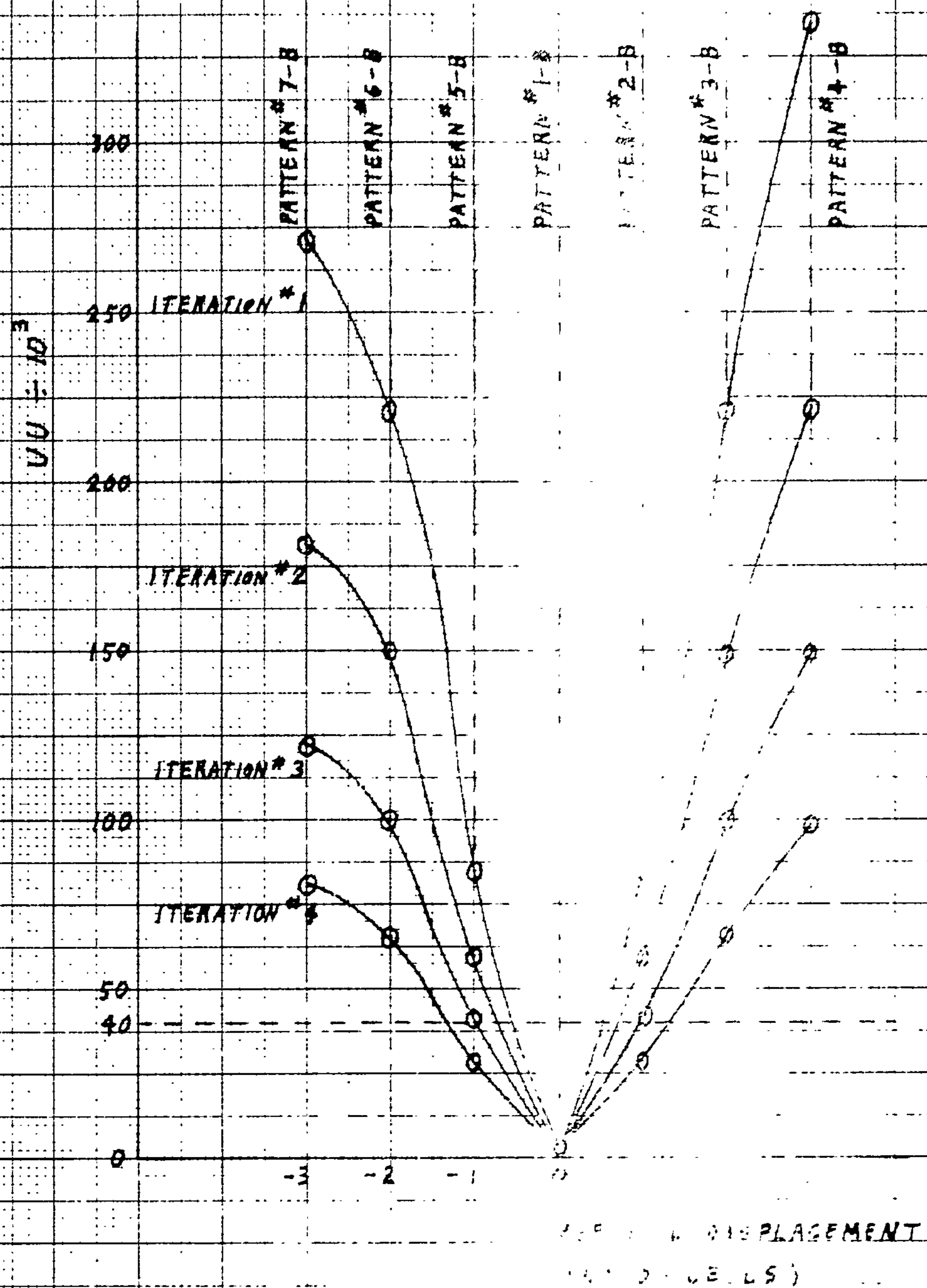


FIG. 27

SENSITIVITY OF MO[illegible] [illegible] VERTICAL DISPLACEMENT OF [illegible] #1-B

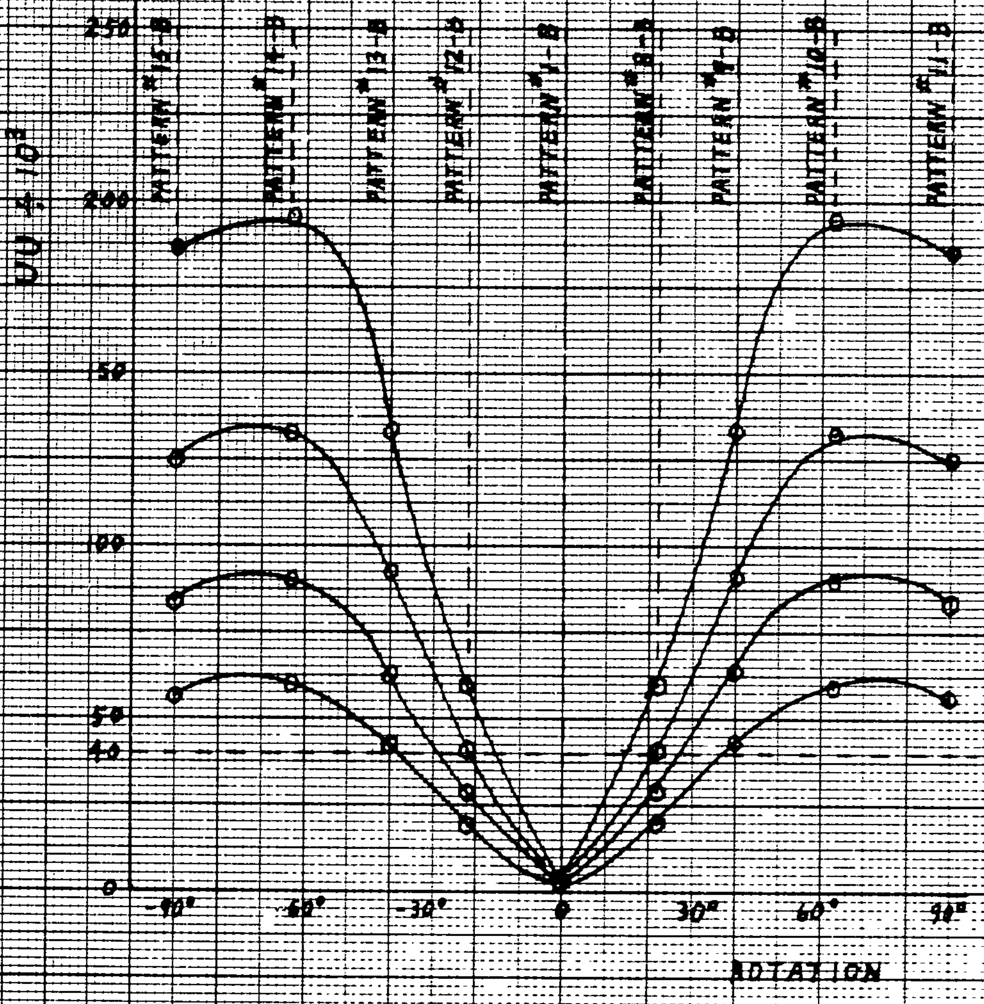


FIG. 28

SENSITIVITY OF MODEL PR-9 TO ROTATION OF PATTERN # 1-B

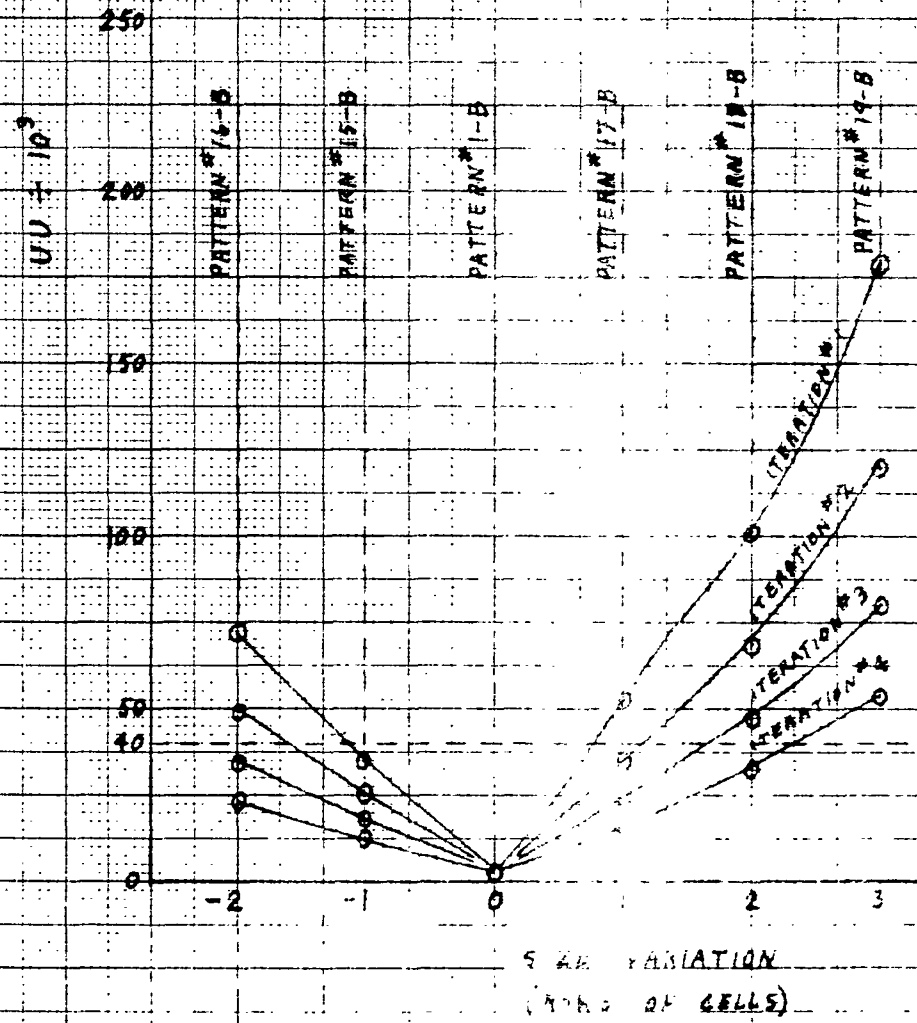


FIG. 29

SENSITIVITY OF MODEL [illegible] TO VARIATIONS IN SIZE OF PATTERN #1-B

#1-B. Diagonal displacement produced larger values of UU than horizontal or vertical displacement. The recognition for a decrease in size was better than for an increase in size, as it was in pattern set "B". In Fig. 34 is shown the sensitivity to variations in shape. The values of UU were comparatively low for patterns #18-C through #22-C, but they increased greatly for patterns #23-C and #24-C. In Fig. 35 is shown the effect upon the sensitivity of varying the metric. Metric #4 provided considerably better recognition capability than any of the other metrics. For this reason, metric # 4 was used in the comparison procedures for set "D".

In pattern set "D", the letter "A" was stored and then compared with several variations of the letter "A" and with various other letters of the alphabet. The results are shown in Fig. 36 (data on pages 107-110 in Appendix C). Patterns #2-D through #7-D are variations of the letter "A", and patterns #8-D through #17-D are the various other letters. There was generally better recognition of variations of the letter "A" than of the other letters, however, this difference does not seem great enough to be of significance when compared to the capability of the visual system in distinguishing between these same patterns.

All of these results indicate that the model of area 17 is capable of pattern invariance recognition to some degree. If the minimum value of UU in the sensitivity

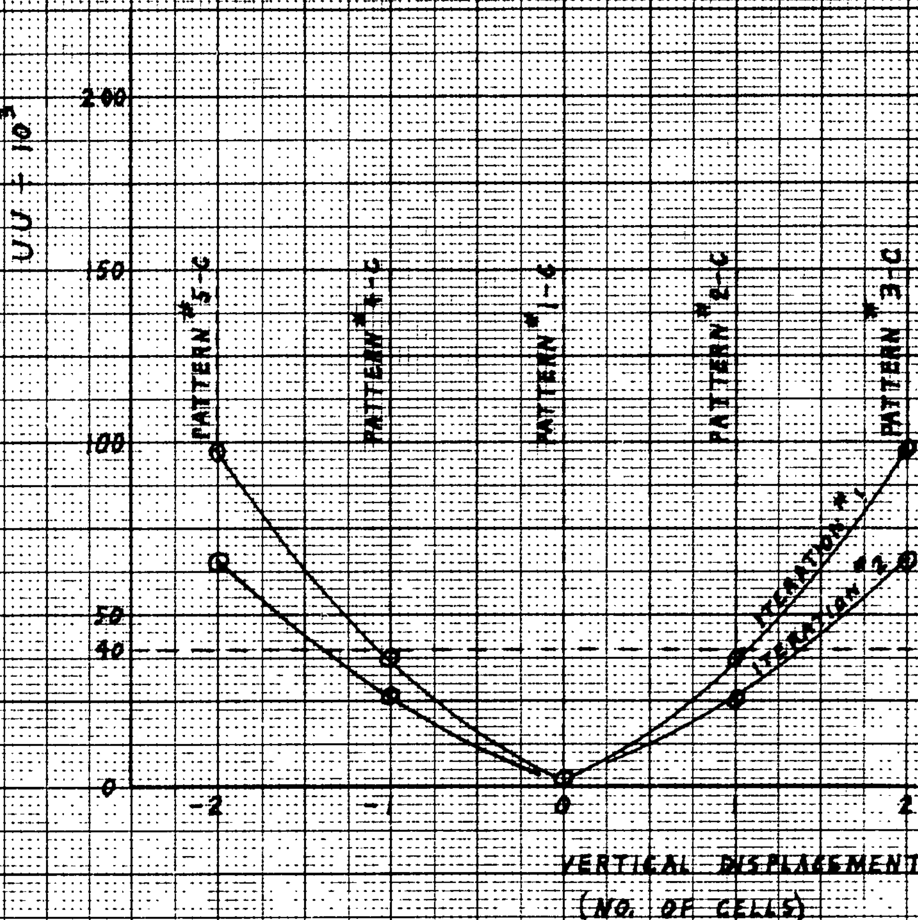


FIG. 30
SENSITIVITY OF MODEL FR-4 TO VERTICAL DISPLACEMENT OF PATTERN #1-C

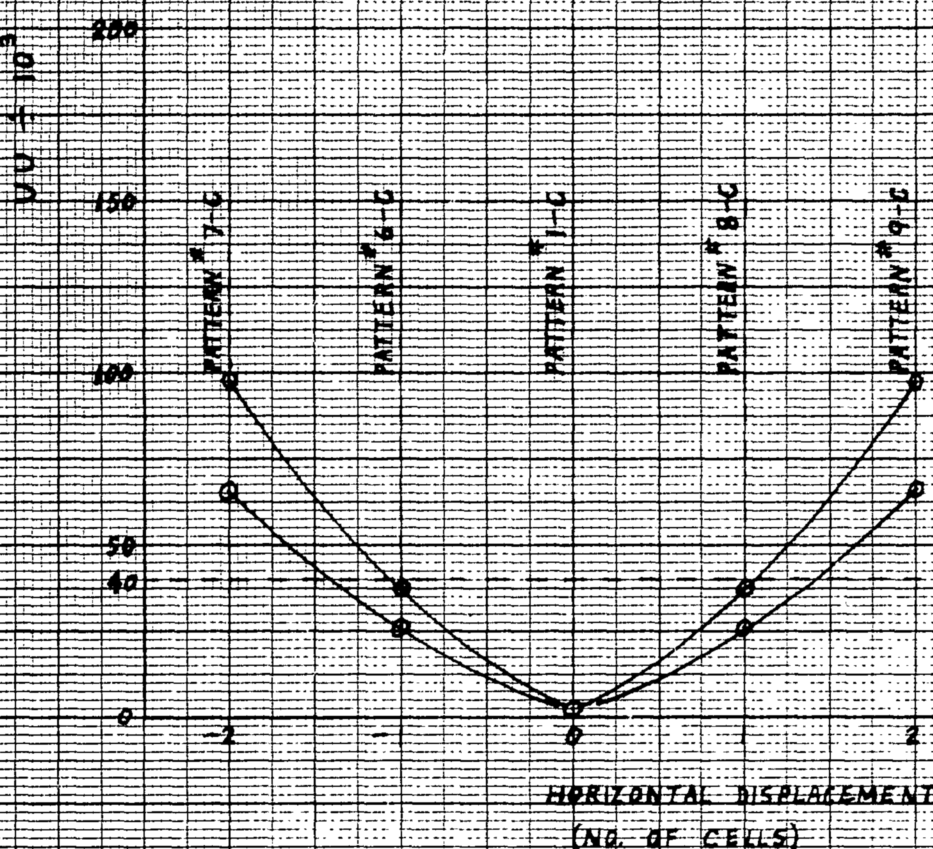


FIG. 31

SENSITIVITY OF MODEL PR-9 TO HORIZONTAL DISPLACEMENT OF PATTERN # 1-C

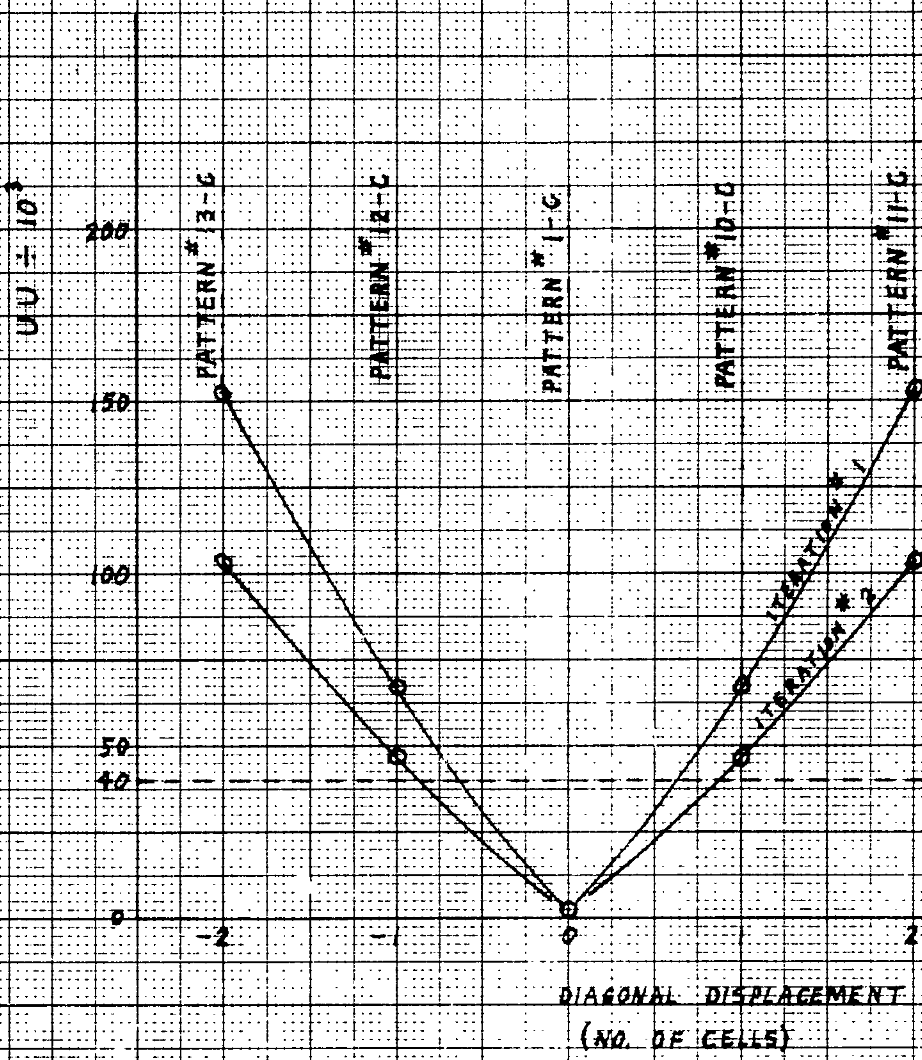


FIG. 32
SENSITIVITY OF MODEL PR-9 TO DIAGONAL DISPLACEMENT OF PATTERN # 1-C

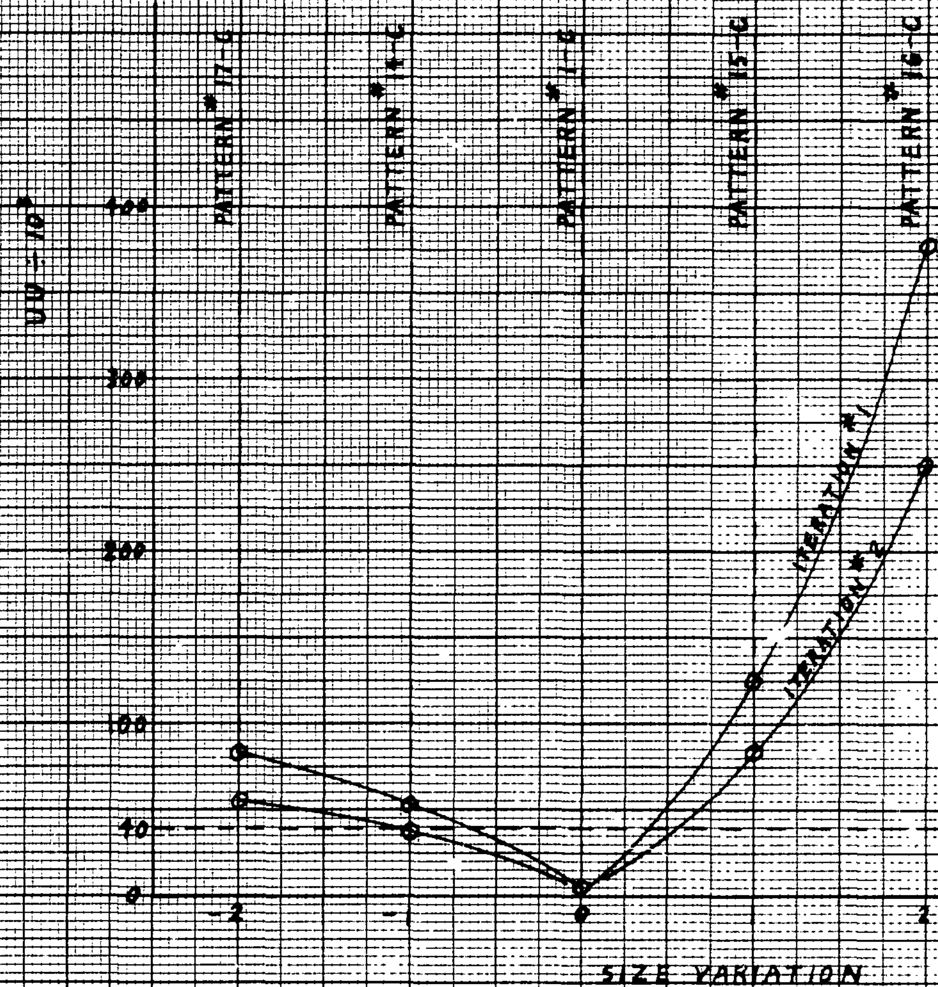


FIG. 33

SENSITIVITY OF PR-9 TO VARIATIONS IN SIZE OF PATTERN # 1-C

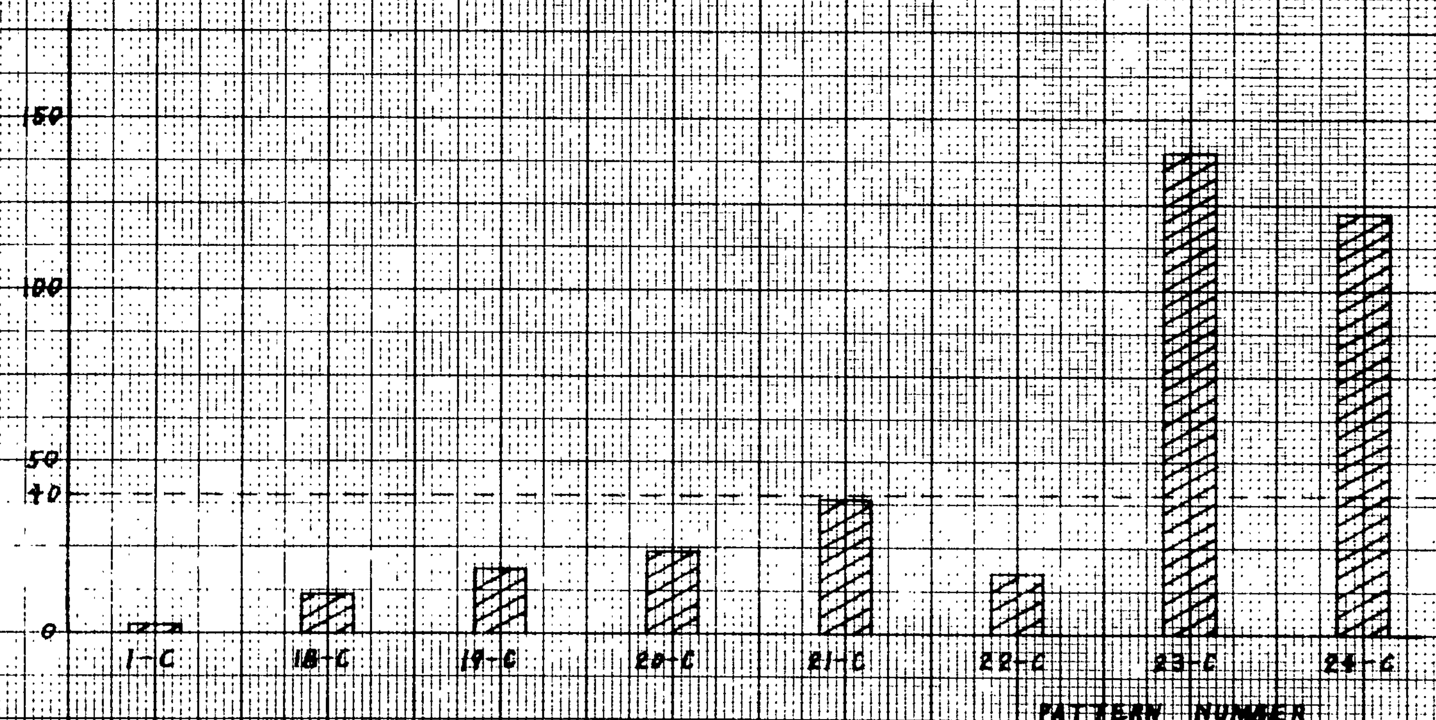


FIG. 34

SENSITIVITY OF MODEL PR-9 TO VARIATIONS IN THE SHAPE OF PATTERN # 1-C

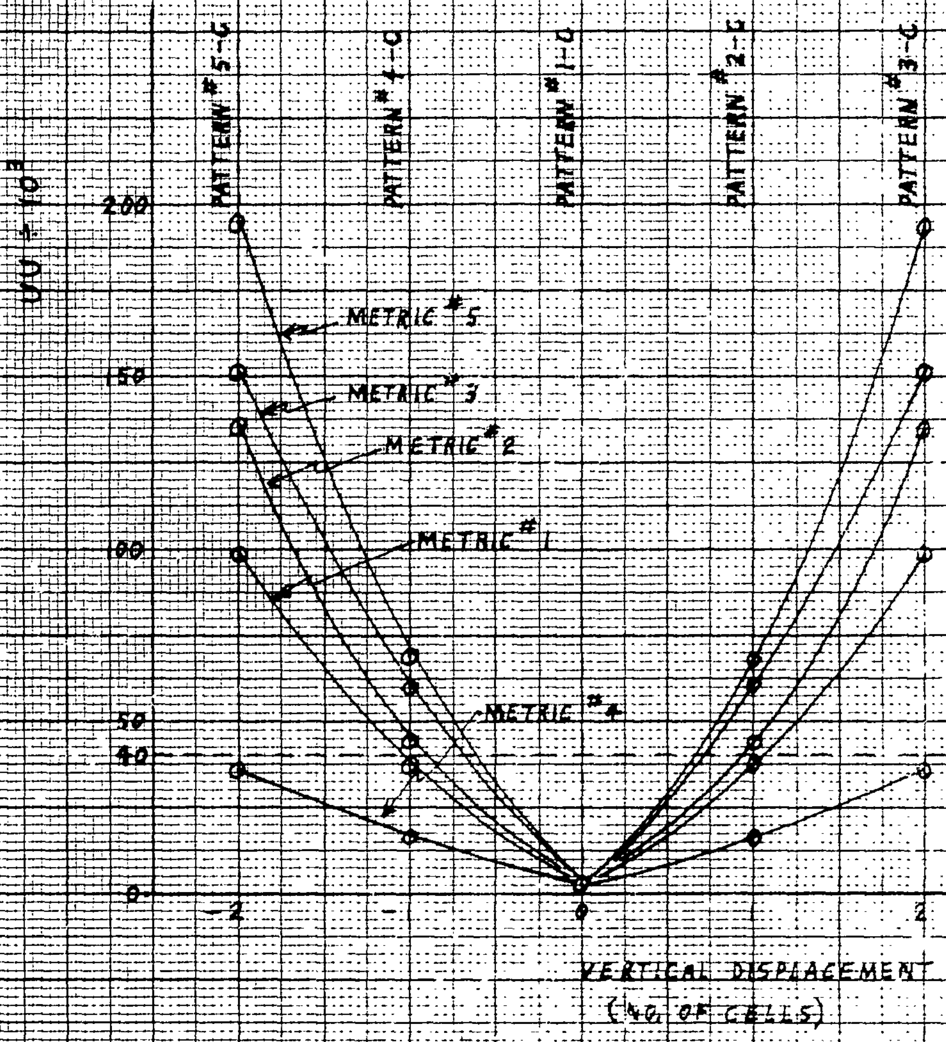


FIG 35

THIS GRAPH SHOWS THE EFFECTS OF VARYING THE CELL COUPLING UPON THE SENSITIVITY OF MODEL 2R-4 TO VERTICAL DISPLACEMENT OF PATTERN #1-C

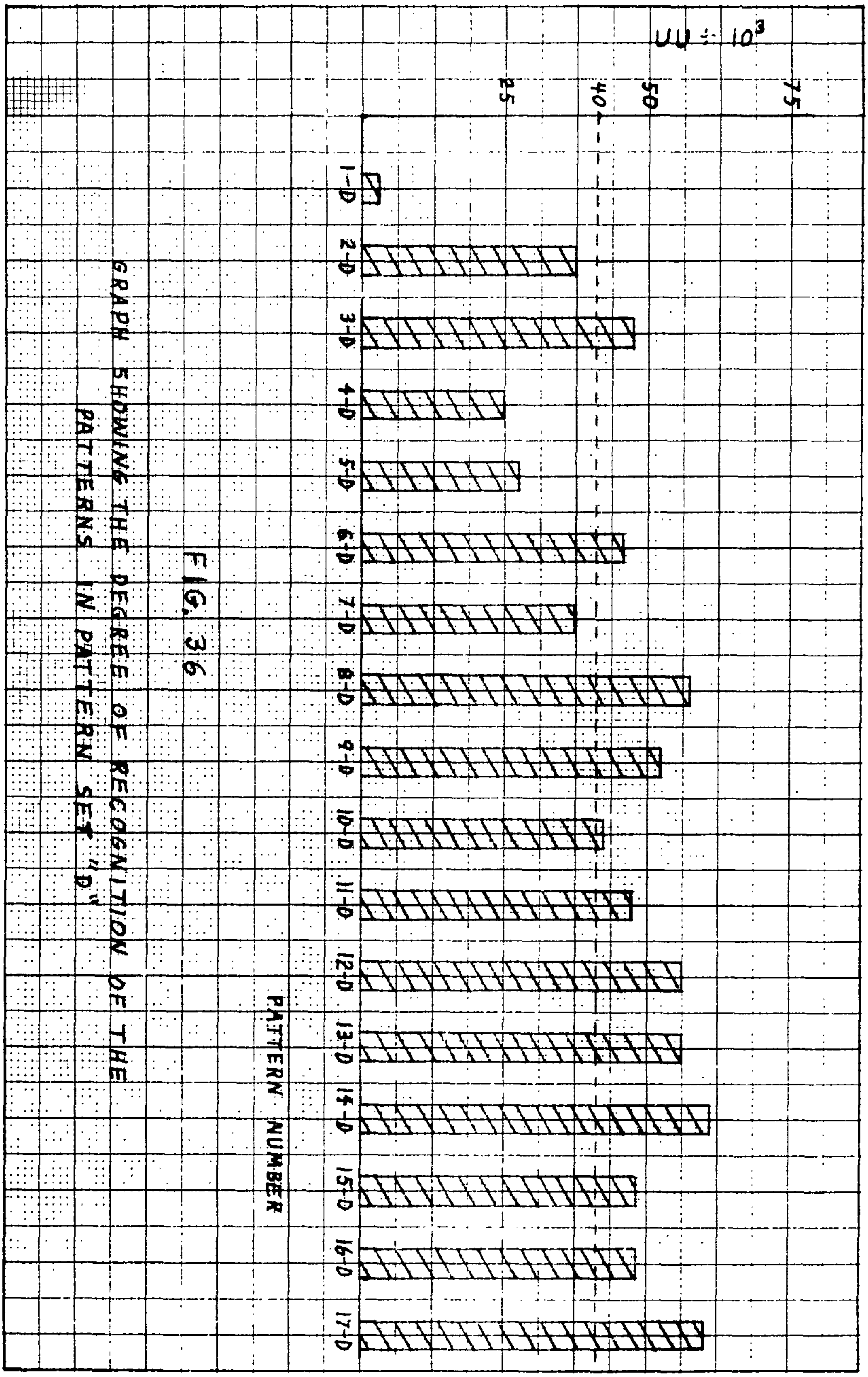


FIG. 36

GRAPH SHOWING THE DEGREE OF RECOGNITION OF THE PATTERNS IN PATTERN SET "D" curves is taken as 100% recognition of a stored pattern, then any slight variation of this pattern produced less than 100% recognition. The human visual system can operate in a mode where there is no intermediate degree of recognition, ie, a pattern is either recognized or not recognized. This indicates the establishment of a threshold function for recognition, which could be duplicated on the model by selecting a certain value of UU for a threshold. If this threshold value is selected as 40,000, above which non-recognition occurs and below which recognition occurs, then a significant degree of pattern invariance recognition is shown by the model. Pattern 1-A and pattern #1-B would be recognized for rotations up to 23 degrees and 16 degrees respectively, and for vertical displacement of one cell width and 1/2 cell width respectively. Pattern #1-B and pattern #1-C would be recognized for size variations up to nearly one cell width and 1/2 cell width respectively. Pattern #1-C would be recognized through most of the shape variations in Fig. 34, and, using metric #4, it would be recognized for vertical displacements of more than two cell widths (Fig. 35). Most of the variations of the letter "A" in Fig. 36 would be recognized and none of the other letters would give recognition. Thus, with a threshold value of 40,000 for UU, the model would be capable of performing pattern invariance recognition for displacements of 1/2 cell width, rotations of 15 degrees, size variations of 1/2 cell width, and slight shape variations for stored patterns similar to the ones in pattern sets A,B,C, and D.

It is concluded that the results of this investigation are of some significance when it is considered that only a portion of the human visual system was simulated, that portion being the basic functional units of area 17 and the short intracortical fibers connecting adjacent units. However, the pattern invariance capabilities of this model are far short of those of the human visual system. It is recommended that further investigation be made by revising the model to include a simulation of the longer subcortical fibers which connect each functional unit of area 17 to many other functional units within area 17. The results obtained by testing this revised model may justify a further revision to include a simulation of areas 18 and 19 and the subcortical fibers connecting each functional unit in area 17 to many units in areas 18 and 19.

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Appendix A

FORTRAN PROGRAM FOR IBM 1620 DIGITAL COMPUTER

160001000000

Input Statements

```
08000      DIMENSIØN P(10,10),SF(10,10),SS(10,10),DE(10,10)
08000   34 READ, N, A, AA, C, CC, D, DD, R
08108      READ, G1, G2, G3, G4
08168      READ, H1, H2, H3, H4
08228      READ, P1, P2, P3, P4
08288      PAUSE
08300      DØ 1 K=1,N
08312      DØ 1 J=1,N
08324   1  READ 31, P(K,J)
08480      PAUSE
08492      DØ 2 K=1,N
08504      DØ 2 J=1,N
08516   2  READ 31, SF(K,J)
08672      PAUSE
08684      DØ 3 K=1,N
08696      DØ 3 J=1,N
08708   3  READ 31, SS(K,J)
08864   31 FØRMAT (177)
08886      ITNØ=0
08910   52 B=0.
08934      U=0.
08958      UU=0.
08982      UUU=0.
```

Basic Iteration (Requires 2 min. 17 sec. on IBM 1620 computer)

```
09006      DØ 4 K=1,N
09018      DØ 4 J=1,N
09030      IF (K-1)5,5,6
09098   5  E=0.
09122      GØ TØ 7
09130   6  E=1.
09154   7  IF(N-K)8,8,9
09222   8  G=0.
09246      GØ TØ 12
09254   9  G=1.
09278   12 IF(J-1)13,13,14
09346   13 H=0.
09370      GØ TØ 15
09378   14 H=1.
09402   15 IF(N-J)16,16,17
09470   16 F=0.
09494      GØ TØ 18
09502   17 F=1.
09526   18 Q=P(K,J)+G1*E*P(K-1,J)+G2*F*P(K,J+1)
09826      SP=Q+G3*G*P(K+1,J)+G4*H*P(K,J-1)+C*SF(K,J)+CC*SS(K,J)
10282      Q=R-SP-E*(H1*DD*SS(K-1,J)+P1*D*SF(K-1,J))
10582      Q=Q-   F*(H2*DD*SS(K,J+1)+P2*D*SF(K,J+1))
10846      Q=Q-   G*(H3*DD*SS(K+1,J)+P3*D*SF(K+1,J))
11110      Q=Q-   H*(H4*DD*SS(K,J-1)+P4*D*SF(K,J-1))
11374      DE(K,J)=Q
```

Error Check

```
11458      IF(E*F*G*H)69,4,69
11546   69 UUU=UUU+Q
11582      IF(Q)71,72,72
11634   71 Q=-Q
11670      U=U+Q
11706      IF(B-Q)73,70,70
11770   73 B=Q
11794      BB=-Q
11830      L=K
11854      M=J
11878      GØ TØ 70
11886   72 U=U+Q
```

Error Check

```
T1922          IF(B-Q)74,70,70
T1986   74     B=Q
T2010          BB=Q
T2034          L=K
T2058          M=J
T2082   70     UU=Q*Q+UU
T2130   4      CONTINUE
T2202          PRINT 100, ITNØ, BB, L, M
T2262          PRINT 101, U, UU, UUU
T2310   100    FØRMAT(/I4, 14X,  F13.7, 5X, I3, 5X, I3)
T2422   101     FØRMAT(/F14.7, 4X, F14.5, 5X, F14.5)
T2492          ITNØ=ITNØ+1
T2528          IF(SENSE SWITCH 3)43,53
T2548   53     IF(SENSE SWITCH 1)40,50
T2568   43     PAUSE
T2580          GØ TØ 34
T2588   50     DØ 51 K=1,N
T2600          DØ 51 J=1,N
T2612          SF(K,J)=SF(K,J )+A*DE(K,J)
T2840   51     SS(K,J)=SS(K,J)+AA*SF(K,J)
T3140          GØ TØ 52
T3148   40     PRINT 102
T3172          102 FØRMAT(/,26H PRINT ØF SF ARRAY FØLLØWS/)
T3258         DØ 140 K=1,N
T3270          IF(SENSE SWITCH 1)24,26
T3290   24 DØ 23 J=1,N
T3302   20     PRINT 1000, SF(K,J)
T3386   23     CONTINUE
T3422   140 PRINT 1001
T3482   1000 FØRMAT (F7.2)
T3504   1001 FØRMAT (/)
T3526          IF(SENSE SWITCH 2)25,26
T3546   25     PRINT 103
T3570   103 FØRMAT(/,34H PUNCH ØF PRINTED SF ARRAY FØLLØWS)
T3668          PAUSE
T3680         DØ 32 K=1,N
T3692          PUNCH 30, SF(K,1), SF(K,2), SF(K,3), SF(K,4), SF(K,5)
T3884   30     FØRMAT (5F7.2)
T3926   32     PUNCH 30, SF(K,6), SF(K,7), SF(K,8), SF(K,9), SF(K,10)
T4154   26     PRINT 104
T4178          104 FØRMAT(/,26H PRINT ØF SS ARRAY FØLLØWS/)
T4264          DØ 141 K=1,N
T4276          IF(SENSE SWITCH 1)27,153
T4296   27    DØ 150 J=1,N
T4308         PRINT 1000, SS(K,J)
T4392   150   CONTINUE
T4428   141 PRINT 1001
T4488          IF (SENSE SWITCH 2)29,153
T4508   29     PRINT 151
T4532   151 FØRMAT(/,34H PUNCH ØF PRINTED SS ARRAY FØLLØWS)
T4630          PAUSE
T4642         DØ 152 K=1,N
T4654          PUNCH 30, SS(K,1), SS(K,2), SS(K,3), SS(K,4), SS(K,5)
T4846   152    PUNCH 30, SS(K,6), SS(K,7), SS(K,8), SS(K,9), SS(K,10)
T5074   153    PRINT 154
T5098          154 FØRMAT(/,26H PRINT ØF DE ARRAY FØLLØWS/)
T5134          DØ 142 K=1,N
T5196          IF(SENSE SWITCH 1)155,50
T5216   155 DØ 157 J=1,N
T5228   156    PRINT 1000, DE(K,J)
```

Output Statements

```
T5312  157  CØNTINUE
T5348  142 PRINT 1001
T5408       GØ TØ 50
T5416       END
END ØF CØMPILATIØN T5415T4500
```

Appendix B

List of Metrics

Format

N, A, AA, C, CC, D, DD, R

G1, G2, G3, G4

H1, H2, H3, H4

P1, P2, P3, P4

Metric 1

10, .1, .01, 1., 1., 1., 1., 0.

.25, .25, .25, .25

.25, .25, .25, .25

.25, .25, .25, .25

Metric 2

10, .1, .01, 1., 1., 1., 1., 0.

.5, .25, .5, .25

.5, .25, .5, .25

.5, .25, .5, .25

Metric 3

10, .1, .01, 1., 1., 1., 1., 0.

.25, .5, .25, .5

.25, .5, .25, .5

.25, .5, .25, .5

Metric 4

10, .1, .01, 1., 1., 1., 1., 0.

0., 0., 0., 0.

0., 0., 0., 0.

0., 0., 0., 0.

Metric 5

10, .1, .01, 1., 1., 1., 1., 0.

.5, .5, .5, .5

.5, .5, .5, .5

.5, .5, .5, .5

Appendix C
Computer Data

STORING PATTERN 1-A WITH METRIC 1

```
          2                  -64.4383460       7         2
      2046.5712000           125463.26000          -2038.84390

          3                  -51.3743100       7         2
      1626.4664000            79977.39100          -1617.69530
          4                  -40.7089860       7         2
      1285.3397000            50517.58100          -1276.61280
         5                  -32.0079860       7         2
      1009.2854000           31542.27100          -1000.50090

-25.5763450    6       2
      799.1120500           19405.58500            -777.10124

      7                     -20.5291330       6         2
      627.0192500           11712.92400           -596.46149
     PRINT ØF SF ARRAY FØLLØWS    .00     .00     .00     .00     .00     .00
    .00    .00    .00    .00
        .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
       -.01   -.01   -.01   -.01   -.01   -.01   -.01   -.01   -.01   -.01
        .33    .27    .28    .28    .28    .28    .28    .28    .27    .33
      -3.59  -2.89  -2.94  -2.94  -2.94  -2.94  -2.94  -2.94  -2.89  -3.59
     -32.58 -36.21 -35.87 -35.89 -35.89 -35.89 -35.89 -35.87 -36.21 -32.58
     -36.50 -39.38 -39.10 -39.12 -39.12 -39.12 -39.12 -39.10 -39.38 -36.50
     -36.14 -39.07 -38.79 -38.81 -38.81 -38.81 -38.81 -38.79 -39.07 -36.14
     -36.49 -39.37 -39.09 -39.10 -39.10 -39.10 -39.10 -39.09 -39.37 -36.49
     -32.91 -36.49 -36.16 -36.17 -36.17 -36.17 -36.17 -36.16 -36.49 -32.91

     PRINT ØF SS ARRAY FØLLØWS    .00     .00     .00     .00     .00     .00
    .00    .00    .00    .00
        .00    .00    .00    .00    .00    .00    .00    .00    .00    .00

     PRINT ØF DE ARRAY FØLLØWS
      8                     -16.3452160       6         2
      486.1280500            6894.74360           -450.50147
     PRINT ØF SF ARRAY FØLLØWS    .00     .00     .00     .00     .00     .00
    .00    .00    .00    .00
        .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
       -.02   -.01   -.01   -.01   -.01   -.01   -.01   -.01   -.01   -.02
        .38    .31    .31    .31    .31    .31    .31    .31    .31    .38
      -3.54  -2.72  -2.79  -2.79  -2.79  -2.79  -2.79  -2.79  -2.72  -3.54
     -34.67 -38.26 -37.87 -37.89 -37.89 -37.89 -37.89 -37.87 -38.26 -34.67
     -38.59 -41.30 -40.99 -41.00 -41.00 -41.00 -41.00 -40.99 -41.30 -38.59
     -38.16 -40.95 -40.63 -40.65 -40.65 -40.65 -40.65 -40.63 -40.95 -38.16
     -38.57 -41.28 -40.97 -40.99 -40.98 -40.98 -40.99 -40.97 -41.28 -38.57
     -35.05 -38.57 -38.19 -38.21 -38.21 -38.21 -38.21 -38.19 -38.57 -35.05
```

```
 PRINT ØF SS ARRAY FØLLØWS      .00      .00      .00      .00      .00      .00
.00    .00     .00     .00
    .00      .00      .00      .00      .00      .00      .00      .00      .00      .00
    .00      .00      .00      .00      .00      .00      .00      .00      .00      .00
    .01      .01      .01      .01      .01      .01      .01      .01      .01      .01
   -.23     -.20     -.20     -.20     -.20     -.20     -.20     -.20     -.20     -.23
  -1.83    -2.11    -2.10    -2.10    -2.10    -2.10    -2.10    -2.10    -2.11    -1.88
  -2.12    -2.33    -2.32    -2.32    -2.32    -2.32    -2.32    -2.32    -2.33    -2.12
  -2.11    -2.32    -2.30    -2.30    -2.30    -2.30    -2.30    -2.30    -2.32    -2.11
  -2.12    -2.33    -2.32    -2.32    -2.32    -2.32    -2.32    -2.32    -2.33    -2.12
  -1.89    -2.12    -2.11    -2.11    -2.11    -2.11    -2.11    -2.11    -2.12    -1.89
 PRINT ØF DE ARRAY FØLLØWS      .00      .00      .00      .00      .00      .00
.00    .00     .00     .00
    .00      .00      .00      .00      .00      .00      .00      .00      .00      .00
   -.07     -.05     -.05     -.05     -.05     -.05     -.05     -.05     -.05     -.07
    .46      .23      .26      .26      .26      .26      .26      .26      .23      .46
   1.04     2.13     1.89     1.91     1.91     1.91     1.91     1.89     2.13     1.04


-17.22 -16.34 -15.84 -15.92 -15.91 -15.91 -15.92 -15.84 -16.34 -17.22
-16.65 -14.44 -14.21 -14.26 -14.26 -14.26 -14.26 -14.21 -14.44 -16.65
-16.03 -14.10 -13.84 -13.90 -13.89 -13.89 -13.90 -13.84 -14.10 -16.03
-16.58 -14.39 -14.16 -14.21 -14.21 -14.21 -14.21 -14.16 -14.39 -16.58
-17.69 -16.57 -16.11 -16.18 -16.17 -16.17 -16.18 -16.11 -16.57 -17.69

 9                    -12.8745610       6         2
 370.8062000           3924.91650           -332.66213
 10                    -9.9936610       6         2
 276.4415600           2134.66950           -237.61964
 11                    -7.6007910       6         2
 199.3639800           1089.83360           -161.05339
 12                    -5.6121190       6         2
 136.9220000            509.91658            -99.45728
 13                    -3.9585110       6         2
  86.2276620            214.83679            -49.98690
 14                    -2.5829250       6         2
  44.8575410             89.89621            -10.33471

 15                     2.1912481       5         9
  47.0323460             62.80157             21.37070
 16                     2.0414548       5         2
  57.8450000             88.62052             46.64681
 17                     2.4828060       7         2
  70.4415010            139.95915             66.72389
 18                     3.0009180       7         2
  86.4631110            200.57196             82.59918
 PRINT ØF SF ARRAY FØLLØWS      .00      .00      .00      .00      .00      .00
.00    .00     .00     .00
    .01      .00      .00      .00      .00      .00      .00      .00      .00      .01
   -.09     -.04     -.05     -.05     -.05     -.05     -.05     -.05     -.04     -.09
    .55      .22      .30      .29      .29      .29      .29      .30      .22      .55
  -1.73     -.42     -.75     -.70     -.71     -.71     -.70     -.75     -.42    -1.73
-42.35 -44.32 -43.70 -43.80 -43.79 -43.79 -43.80 -43.70 -44.32 -42.35
-44.65 -44.97 -44.76 -44.80 -44.80 -44.80 -44.80 -44.76 -44.97 -44.65
-43.91 -44.66 -44.35 -44.41 -44.40 -44.40 -44.41 -44.35 -44.66 -43.91
-44.55 -44.93 -44.71 -44.75 -44.75 -44.75 -44.75 -44.71 -44.93 -44.55
-42.90 -44.54 -44.00 -44.09 -44.08 -44.08 -44.09 -44.00 -44.54 -42.90
```

```
PUNCH ØF PRINTED SF ARRAY FØLLØWS
PRINT ØF SS ARRAY FØLLØWS    .00     .00     .00     .00     .00     .00
.00    .00    .00    .00
   .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
   .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
   .06    .04    .04    .04    .04    .04    .04    .04    .04    .06
  -.49   -.34   -.37   -.36   -.36   -.36   -.36   -.37   -.34   -.49
 -5.91  -6.42  -6.35  -6.36  -6.36  -6.36  -6.36  -6.35  -6.42  -5.91
 -6.47  -6.81  -6.77  -6.77  -6.77  -6.77  -6.77  -6.77  -6.81  -6.47
 -6.39  -6.76  -6.71  -6.72  -6.71  -6.71  -6.72  -6.71  -6.76  -6.39
 -6.46  -6.81  -6.76  -6.77  -6.77  -6.77  -6.77  -6.76  -6.81  -6.46
 -5.97  -6.46  -6.40  -6.40  -6.40  -6.40  -6.40  -6.40  -6.46  -5.97

PUNCH ØF PRINTED SS ARRAY FØLLØWS
PRINT ØF DE ARRAY FØLLØWS    .00     .00     .00     .00     .00     .00
.00    .00    .00    .00
   .01    .00    .00    .00    .00    .00    .00    .00    .00    .01
  -.04    .01    .00    .00    .00    .00    .00    .00    .01   -.04
  -.10   -.30   -.20   -.22   -.22   -.22   -.22   -.20   -.30   -.10
  1.83   1.72   1.51   1.58   1.57   1.57   1.58   1.51   1.72   1.83
  -.71    .96    .95    .88    .89    .89    .88    .95    .96   -.71
  1.21   3.00   2.66   2.69   2.69   2.69   2.69   2.66   3.00   1.21
  1.20   2.65   2.46   2.46   2.46   2.46   2.46   2.46   2.65   1.20
  1.26   2.98   2.66   2.68   2.69   2.69   2.68   2.66   2.98   1.26
  -.60   1.27   1.15   1.11   1.12   1.12   1.11   1.15   1.27   -.60
```

STORING PATTERN 1-A WITH METRIC 2

```
0                 -125.0000000      7       2
4000.0000000      460000.00000        -4000.00000
1                 -95.0156300       7       9
3022.8248000      263663.29000        -3002.62480
2                 -71.8591520       7       2
2272.9565000      149920.91000        -2242.55750
3                 -53.9776650       7       2
1697.7116000      84362.65800         -1663.62690
4                 -40.1717920       7       2
1256.6101000      46829.94900         -1222.93150
5                 -29.5150870       7       2
922.8224500       25534.33400          -887.70787
6                 -21.7043060       6       2
683.2345800       13597.98500          -632.93819
7                 -16.7156160       6       2
506.0210100       7020.07840           -439.52190
8                 -12.8023180       6       2
364.4101100       3482.34130           -292.87760
9                 -9.7238220        6       2
254.2921300       1648.27790           -181.87626
10                -7.2944400        6       2
```

```
 168.6150500           752.53325              -98.02510
 11                   -5.3707880         6          2
 101.9184600           360.74414              -34.84459
 12                    4.2438769         5          9
  75.4964820           229.41026               12.60734
 13                    4.1210578         5          2
  93.2963160           224.35367               48.09962
 14                    3.9585186         5          2
 105.7203600           273.46441               74.50490
 15                    3.7729315         5          9
 113.7902500           339.44398               94.01240
 PRINT ØF SF ARRAY FØLLØWS    -.01      .00      .00      .00      .00      .00      .00      .
00    .00    -.01
    .10     .06     .07     .07     .07     .07     .07     .07     .06     .10
   -.60    -.36    -.39    -.39    -.39    -.39    -.39    -.39    -.36    -.60
   2.30    1.26    1.45    1.43    1.43    1.43    1.43    1.45    1.26    2.30
  -5.03   -2.35   -2.88   -2.82   -2.82   -2.82   -2.82   -2.88   -2.35   -5.03
 -40.03  -43.05  -42.38  -42.47  -42.46  -42.46  -42.47  -42.38  -43.05  -40.03
 -47.47  -46.74  -46.79  -46.80  -46.79  -46.79  -46.80  -46.79  -46.74  -47.47
 -43.98  -44.76  -44.55  -44.58  -44.58  -44.58  -44.58  -44.55  -44.76  -43.98
 -46.88  -46.39  -46.40  -46.41  -46.41  -46.41  -46.41  -46.40  -46.39  -46.88
 -42.33  -44.32  -43.84  -43.90  -43.89  -43.89  -43.90  -43.84  -44.32  -42.33

 PUNCH ØF PRINTED SF ARRAY FØLLØWS
 PRINT ØF SS ARRAY FØLLØWS     .00      .00      .00      .00      .00      .00      .00      .
00     .00     .00
    .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
   -.03    -.02    -.02    -.02    -.02    -.02    -.02    -.02    -.02    -.03
    .19     .14     .15     .15     .15     .15     .15     .15     .14     .19
   -.86    -.64    -.67    -.67    -.67    -.67    -.67    -.67    -.64    -.86
  -4.72   -5.16   -5.11   -5.11   -5.11   -5.11   -5.11   -5.11   -5.16   -4.72
  -5.79   -5.95   -5.94   -5.94   -5.94   -5.94   -5.94   -5.94   -5.95   -5.79
  -5.52   -5.76   -5.74   -5.74   -5.74   -5.74   -5.74   -5.74   -5.76   -5.52
  -5.75   -5.93   -5.91   -5.91   -5.91   -5.91   -5.91   -5.91   -5.93   -5.75
  -4.92   -5.30   -5.26   -5.26   -5.26   -5.26   -5.26   -5.26   -5.30   -4.92

 PUNCH ØF PRINTED SS ARRAY FØLLØWS
 PRINT ØF DE ARRAY FØLLØWS    -.03     -.02     -.02     -.02     -.02     -.02     -.02     -.
02    -.02    -.03




    .19     .07     .10     .10     .10     .10     .10     .10     .07     .19
   -.57    -.09    -.21    -.19    -.19    -.19    -.19    -.21    -.09    -.57
    .40    -.74    -.36    -.42    -.41    -.41    -.42    -.36    -.74     .40
   2.77    3.77    3.13    3.26    3.24    3.24    3.26    3.13    3.77    2.77
  -1.10    -.85    -.39    -.52    -.50    -.50    -.52    -.39    -.85   -1.10
   1.07    3.58    2.99    3.07    3.06    3.06    3.07    2.99    3.58    1.07
   2.59    3.00    3.04    3.01    3.02    3.02    3.01    3.04    3.00    2.59
   1.61    3.65    3.19    3.24    3.24    3.24    3.24    3.19    3.65    1.61
  -1.50    -.10    -.03    -.09    -.08    -.08    -.09    -.03    -.10   -1.50

 16                    4.1652310         9          2
 120.6436900           404.19094              108.28964
```

STORING PATTERN 1-A WITH METRIC 3

```
 0                  -125.0000000        7          2
4000.0000000         477500.00000          -4000.00000
 1                  -95.0156300         7          2
3007.6747000         272339.95000          -3002.62470
 2                  -71.8033600         7          2
2249.5197000         153994.83000          -2242.55750
 3                  -53.8413980         7          2
1670.6396000          86082.31400          -1663.62670
 4                  -40.5201930         6          2
1239.3314000          47381.40400          -1222.93140
 5                  -30.9943340         6          2
 918.6447500          25535.09300           -887.70784
 6                  -23.4853710         6          2
 671.3981600          13363.72300           -632.93821
 7                  -17.5606950         6          2
 480.8345200           6707.73350           -439.52186
 8                  -12.8821640         6          2
 334.3391600           3166.41620           -292.87758
 9                   -9.1851480         6          2
 222.0412600           1361.15440           -181.87627
10                   -6.2622760         6          2
 136.0188700            505.60267            -98.02511
11                   -3.9509050         6          2
  69.9607250            155.35951            -34.84464
12                    2.6560663         5          2
  42.0636700             62.46703             12.60731
13                    2.4317432         5          2
  57.4688690             91.08150             48.09960
 PRINT ØF SF ARRAY FØLLØWS      .00      .00      .00      .00      .00      .00      .00
00     .00      .00
     .00      .00      .00      .00      .00      .00      .00      .00      .00      .00
    -.05     -.01     -.02     -.02     -.02     -.02     -.02     -.02     -.01     -.05
     .46      .08      .19      .17      .18      .18      .17      .19      .08      .46
   -2.34     -.01     -.81     -.65     -.67     -.67     -.65     -.81     -.01    -2.34
  -41.25   -46.76   -44.53   -45.03   -44.96   -44.96   -45.03   -44.53   -46.76   -41.25
  -44.06   -46.86   -45.55   -45.87   -45.82   -45.82   -45.87   -45.55   -46.86   -44.06
  -43.49   -46.75   -45.30   -45.64   -45.59   -45.59   -45.64   -45.30   -46.75   -43.49
  -44.01   -46.85   -45.52   -45.84   -45.79   -45.79   -45.84   -45.52   -46.85   -44.01
  -41.72   -46.84   -44.73   -45.20   -45.14   -45.14   -45.20   -44.73   -46.84   -41.72

 PUNCH ØF PRINTED SF ARRAY FØLLØWS
 PRINT ØF SS ARRAY FØLLØWS      .00      .00      .00      .00      .00      .00      .00
00     .00      .00
     .00      .00      .00      .00      .00      .00      .00      .00      .00      .00
     .00      .00      .00      .00      .00      .00      .00      .00      .00      .00
     .03      .01      .02      .02      .02      .02      .02      .02      .01      .03
    -.34     -.18     -.22     -.21     -.21     -.21     -.21     -.22     -.18     -.34
   -4.04    -4.79    -4.64    -4.66    -4.66    -4.66    -4.66    -4.64    -4.79    -4.04
   -4.42    -5.00    -4.88    -4.90    -4.90    -4.90    -4.90    -4.88    -5.00    -4.42
   -4.38    -4.98    -4.86    -4.88    -4.87    -4.87    -4.88    -4.86    -4.98    -4.38



   -4.42    -5.00    -4.88    -4.90    -4.90    -4.90    -4.90    -4.88    -5.00    -4.42
   -4.07    -4.81    -4.66    -4.68    -4.68    -4.68    -4.68    -4.66    -4.81    -4.07
```

```
PUNCH OF PRINTED SS ARRAY FØLLØWS
PRINT ØF DE ARRAY FØLLØWS     .00     .00     .00     .00     .00     .00     .00    .
00    .00    .00
   .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
  -.06    .03    .00    .00    .00    .00    .00    .00    .03   -.06
   .13   -.40   -.10   -.18   -.16   -.16   -.18   -.10   -.40    .13
  1.48   2.43   1.31   1.71   1.63   1.63   1.71   1.31   2.43   1.48
 -3.62   -.67    .18   -.48   -.30   -.30   -.48    .18   -.67  -3.62
 -2.28   2.15   1.59   1.41   1.49   1.49   1.41   1.59   2.15  -2.28
 -2.02   1.69   1.51   1.22   1.32   1.32   1.22   1.51   1.69  -2.02
 -2.22   2.12   1.60   1.41   1.49   1.49   1.41   1.60   2.12  -2.22
 -3.76   -.27    .28   -.30   -.13   -.13   -.30    .28   -.27  -3.76
```

COMPARING PATTERN 2-A WITH STORED PATTERN 1-A
(PATTERN 1-A STORED WITH METRIC 1)

```
                                                          160001000000
 0                     -87.7975000       4          2
 1645.8200000          123121.66000         -1518.02000
 1                     -72.3411760       4          2
 1340.2829000           82302.73800         -1183.47790
 2                     -59.4837390       4          2
 1089.7859000           54938.51700          -913.06305
 3                     -48.7839840       4          2
 884.5267600            36615.99000          -694.61435
 4                     -39.8764640       4          2
 738.5342300            24368.07200          -518.26747
 5                     -32.4583660       4          2
 627.1479400            16199.43300          -376.02460
 6                     -26.2786590       4          2
 547.0128000            10767.95700          -261.40153
 7                     -21.1291480       4          2
 477.8148300             7170.93780          -169.14177
 8                     -16.8370320       4          2
 418.0807200             4801.27820           -94.98491
 9                     -13.2590500       4          2
 366.5287900             3250.89240           -35.47798
 10                    -10.2759490       4          2
 322.0455300             2245.64660            12.17651
 11                     -7.7898080       4          2
 283.8269700             1601.59130            50.24512
PRINT ØF SF ARRAY FØLLØWS    -.04    -.03    -.03    -.03    -.03    -.03    -.03
03    -.03    -.04
   .52    .35    .37    .37    .37    .37    .37    .37    .35    .52
 -3.19  -1.98  -2.17  -2.15  -2.15  -2.15  -2.15  -2.17  -1.98  -3.19
-39.11 -42.63 -41.94 -42.03 -42.02 -42.02 -42.03 -41.94 -42.63 -39.11
-39.66 -41.80 -41.76 -41.68 -41.70 -41.70 -41.68 -41.76 -41.80 -39.66
-43.91 -43.36 -42.99 -43.14 -43.10 -43.10 -43.14 -42.99 -43.36 -43.91
-40.91 -40.18 -40.31 -40.30 -40.30 -40.30 -40.30 -40.31 -40.18 -40.91
-40.88 -40.67 -40.54 -40.59 -40.59 -40.59 -40.59 -40.54 -40.67 -40.88
-41.30 -40.54 -40.64 -40.63 -40.63 -40.63 -40.63 -40.64 -40.54 -41.30
-41.19 -41.28 -40.95 -41.06 -41.04 -41.04 -41.06 -40.95 -41.28 -41.19
```

```
PRINT ØF SS ARRAY FØLLØWS    .00     .00     .00     .00     .00     .00     .00    .
00    .00    .00
   .03    .02    .02    .02    .02    .02    .02    .02    .02    .03
  -.34   -.27   -.28   -.28   -.28   -.28   -.28   -.28   -.27   -.34
 -2.93  -3.32  -3.23  -3.28  -3.28  -3.28  -3.28  -3.28  -3.32  -2.93
 -3.61  -3.67  -3.72  -3.70  -3.70  -3.70  -3.70  -3.72  -3.67  -3.61
-10.84 -11.41 -11.29 -11.31 -11.31 -11.31 -11.31 -11.29 -11.41 -10.84
-11.18 -11.48 -11.44 -11.44 -11.44 -11.44 -11.44 -11.44 -11.48 -11.18
-11.06 -11.44 -11.37 -11.39 -11.38 -11.38 -11.39 -11.37 -11.44 -11.06
-11.19 -11.50 -11.44 -11.46 -11.46 -11.46 -11.46 -11.44 -11.50 -11.19
-10.62 -11.19 -11.08 -11.09 -11.09 -11.09 -11.09 -11.08 -11.19 -10.62

PRINT ØF DE ARRAY FØLLØWS    -.07    -.03    -.04    -.04    -.04    -.04    -.04    -.
04   -.03   -.07
   .24   -.04    .02    .02    .02    .02    .02    .02   -.04    .24
  1.97   2.65   2.33   2.39   2.38   2.38   2.39   2.33   2.65   1.97
 -9.75  -7.78  -7.46  -7.58  -7.56  -7.56  -7.58  -7.46  -7.78  -9.75
 -8.64  -7.14  -6.91  -6.93  -6.94  -6.94  -6.93  -6.91  -7.14  -8.64
  4.80   6.32   5.90   5.91   5.93   5.93   5.91   5.90   6.32   4.80
  4.19   4.35   4.16   4.23   4.21   4.21   4.23   4.16   4.35   4.19
  3.63   4.02   3.91   3.92   3.92   3.92   3.92   3.91   4.02   3.63
  3.94   4.34   4.12   4.18   4.17   4.17   4.18   4.12   4.34   3.94
  3.05   3.94   3.72   3.72   3.73   3.73   3.72   3.72   3.94   3.05

 12                       6.3451790       6        2
 251.4503300              1195.49190              80.56389
```

COMPARING PATTERN 2-A WITH STORED PATTERN 1-A
(METRIC 2 USED IN STORING PATTERN 1-A)

```
0                   -89.0800000        4        2
1662.5950000        121797.60000           -1522.13500
1                   -73.5271250        4        2
1356.0166000         81285.92800           -1185.82780
2                   -60.5785560        4        2
1104.5103000         54162.90900            -914.03357
3                   -49.7930090        4        2
898.2490800          36028.33500            -694.51238
4                   -40.8049220        4        2
729.1840300          23925.97100            -517.33803
5                   -33.3113270        4        2
616.1172500          15869.43200            -374.46225
6                   -27.0610170        4        2
538.0216600          10523.92300            -259.36026
7                   -21.8455980        4        2
470.5559500           6992.54870            -166.74357
8                   -17.4921080        4        2
412.2947400           4672.83180             -92.32562
9                   -13.8569230        4        2
361.9958400           3160.30310             -32.63294
10                  -10.8207150        4        2
318.5989000           2183.64840              15.14864
11                   -8.2842920        4        2
281.5121200           1561.10250              53.29877
```

COMPARING PATTERN 2-A WITH STORED PATTERN 1-A
(METRIC 3 USED IN STORING PATTERN 1-A)

0	-87.7150000	4	2
1623.4250000	123477.88000		-1558.06500

THE FOLLOWING SETS OF PATTERN COMPARISON DATA WERE OBTAINED BY USING THE STORED SF ARRAY OF PATTERN 1-A AS THE SS ARRAY DURING THE COMPARISON. THE SF ARRAY EQUALS ZERO. METRIC 1 USED IN STORING PATTERN 1-A AND IN EACH COMPARISON.

COMPARING PATTERN 1-A WITH STORED PATTERN 1-A

0	-11.0150000	8	3
348.4150000	3656.31590		-348.13500
1	-8.8070770	8	3
278.3631900	2364.25550		-278.03032
2	-7.0460260	6	4
222.5896900	1520.64730		-221.25434
3	-5.7758690	6	4
179.4507400	971.62421		-175.29140

COMPARING PATTERN 2-A WITH STORED PATTERN 1-A

0	-88.1200000	5	3
1948.3150000	131860.30000		-1948.13500
1	-72.2997980	4	2
1561.2908000	87537.31200		-1556.09080
2	-59.4018580	4	2
1246.5927000	57929.17400		-1238.74370
3	-48.6771020	4	2
990.8079400	38177.00900		-981.94735

COMPARING PATTERN 3-A WITH STORED PATTERN 1-A

0	77.1800000	6	2
1427.0450000	96840.93200		1251.86500
1	63.7147330	7	2
1153.9605000	65204.55700		1000.03240
2	52.5735100	7	2
950.5055000	43782.63900		796.23661
3	43.2733780	7	2
779.1956100	29291.33500		631.36470

COMPARING PATTERN 8-A WITH STORED PATTERN 1-A

0	-87.9350000	5	9
976.4000000	45887.37000		-348.13500
1	-72.7670110	5	9
791.7542600	31441.12500		-278.03033
2	-60.0806640	5	9
642.2272100	21544.62100		-221.25426
3	-49.4656410	5	9
520.7804300	14761.12200		-175.29136

COMPARING PATTERN 9-A WITH STORED PATTERN 1-A

0	-100.3175000	4	9
1358.4450000	78580.11700		-348.13500
1	-81.9591730	4	9
1100.9943000	52646.96300		-278.03033
2	-66.7583260	4	9
889.7649200	35180.42600		-221.25427
3	-54.1735250	4	9
716.7860000	23432.41000		-175.29132

COMPARING PATTERN 4-A WITH STORED PATTERN 1-A

0	-75.6200000	5	3
1077.4050000	53053.17800		-1048.13500
1	-63.4232610	5	2
858.0473500	36252.60800		-849.88656
2	-53.2868510	5	2
695.9379300	24810.62300		-687.82964
3	-44.7225530	5	2
564.6406200	17003.05900		-555.28849

COMPARING PATTERN 5-A WITH STORED PATTERN 1-A

0	-83.1200000	5	3
2401.9450000	177204.90000		-1148.13500
1	-72.2997980	4	2
1934.4004000	118396.62000		-917.06077
2	-59.4018580	4	2
1569.8156000	78870.67600		-730.03038
3	-48.6771020	4	2
1269.6983000	52337.95700		-578.69461

COMPARING PATTERN 7-A WITH STORED PATTERN 1-A

```
   0                  -100.3175000        4       9
3088.1450000          257072.88000            -348.13500
   1                  -80.6966730         4       9
2483.9276000          167888.59000            -278.03029
   2                  -64.6671200         4       9
1997.8357000          109085.08000            -221.25419
   3                  -51.5775170         4       9
1601.1347000           70430.39300            -175.29131
   4                  -40.8944000         4       9
1277.0117000           45116.27500            -138.09991
   5                  -32.1808550         4       9
1012.7165000           28616.84800            -108.02209
```

STORING PATTERN 1-B WITH METRIC 1

```
 0                  -100.0000000        6       2
 2400.0000000        205000.00000         -2400.00000
 1                   -80.7468750        6       2
 1927.1924000        134739.95000         -1917.09280
PRINT ØF SF ARRAY FØLLØWS
   .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
   .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
   .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
 -1.25  -1.25  -1.25  -1.25  -1.25  -1.25  -1.25  -1.25  -1.25  -1.25
 -7.50  -8.75  -8.75  -8.75  -8.75  -8.75  -8.75  -8.75  -8.75  -7.50
 -8.75 -10.00 -10.00 -10.00 -10.00 -10.00 -10.00 -10.00 -10.00  -8.75
 -7.50  -8.75  -8.75  -8.75  -8.75  -8.75  -8.75  -8.75  -8.75  -7.50

PRINT ØF SS ARRAY FØLLØWS

PRINT ØF DE ARRAY FØLLØWS

 2                   -64.9213020        6       2
 1541.7209000         88191.96100         -1526.26720
 3                   -51.9211870        6       2
 1227.5953000         57422.04100         -1210.06110
 4                   -41.2500270        6       2
 971.7473200          37140.90300          -954.31440
 5                   -32.4983280        6       2
 765.0351600          23823.16300          -747.55026
 6                   -25.5302110        5       2
 624.3491400          15120.33200          -580.46270
 7                   -20.4793280        5       2
 506.4354700           9469.13430          -445.50964
 8                   -16.2946820        5       2
 407.5889100           5829.93270          -336.57800
 9                   -12.8259510        5       2
 324.7132000           3512.27830          -248.71400
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10                       -9.9492220       5        2
 255.2207000              2058.39250           -177.90328
11                       -7.5623140       5        2
 197.1590200              1165.44700           -120.89396
12                       -5.5809280       5        2
 149.5980000               633.69381            -75.05141
13                       -3.9355010       7        2
 110.3357400               331.87196            -38.24204
14                       -2.5685930       7        2
  77.9998500               174.14894             -8.73774
15                        2.1866732       8        2
  65.3960100               104.75457             14.86052
16                        2.0975730       6        2
  55.6262250                87.75652             33.68556
PRINT ØF SF ARRAY FØLLØWS
    .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
   -.08    -.04    -.05    -.05    -.05    -.05    -.05    -.05    -.04    -.08
    .56     .28     .33     .33     .33     .33     .33     .33     .28     .56
  -2.12    -.81   -1.10   -1.06   -1.07   -1.07   -1.06   -1.10    -.81   -2.12
 -41.90  -44.25  -43.64  -43.72  -43.71  -43.71  -43.72  -43.64  -44.25  -41.90
 -45.23  -45.68  -45.46  -45.50  -45.50  -45.50  -45.50  -45.46  -45.68  -45.23
 -41.90  -44.25  -43.64  -43.72  -43.71  -43.71  -43.72  -43.64  -44.25  -41.90
  -2.12    -.81   -1.10   -1.06   -1.07   -1.07   -1.06   -1.10    -.81   -2.12
    .56     .28     .33     .33     .33     .33     .33     .33     .28     .56
   -.08    -.04    -.05    -.05    -.05    -.05    -.05    -.05    -.04    -.08

PUNCH ØF PRINTED SF ARRAY FØLLØWS




PRINT ØF SS ARRAY FØLLØWS
    .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
    .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
    .05     .03     .04     .04     .04     .04     .04     .04     .03     .05
   -.46    -.33    -.35    -.35    -.35    -.35    -.35    -.35    -.33    -.46
  -5.06   -5.53   -5.47   -5.48   -5.48   -5.48   -5.48   -5.47   -5.53   -5.06
  -5.63   -5.95   -5.91   -5.91   -5.91   -5.91   -5.91   -5.91   -5.95   -5.63
  -5.06   -5.53   -5.47   -5.48   -5.48   -5.48   -5.48   -5.47   -5.53   -5.06
   -.46    -.33    -.35    -.35    -.35    -.35    -.35    -.35    -.33    -.46
    .05     .03     .04     .04     .04     .04     .04     .04     .03     .05
    .00     .00     .00     .00     .00     .00     .00     .00     .00     .00

PUNCH ØF PRINTED SS ARRAY FØLLØWS
PRINT ØF DE ARRAY FØLLØWS
    .01     .00     .00     .00     .00     .00     .00     .00     .00     .01
   -.05     .00    -.01    -.01    -.01    -.01    -.01    -.01     .00    -.05
   -.03    -.27    -.17    -.19    -.18    -.18    -.19    -.17    -.27    -.03
   1.96    2.03    1.79    1.85    1.84    1.84    1.85    1.79    2.03    1.96
  -2.22    -.48    -.42    -.49    -.48    -.48    -.49    -.42    -.48   -2.22
   -.23    2.09    1.70    1.73    1.73    1.73    1.73    1.70    2.09    -.23
  -2.22    -.48    -.42    -.49    -.48    -.48    -.49    -.42    -.48   -2.22
   1.96    2.03    1.79    1.85    1.84    1.84    1.85    1.79    2.03    1.96

17                        2.7781910       6        2
  55.9839550               100.26452             48.65413
```

THE FOLLOWING SETS OF PATTERN COMPARISON DATA WERE OBTAINED BY USING THE STORED SF ARRAY OF PATTERN 1-B AS THE SS ARRAY DURING THE COMPARISON. THE SF ARRAY IS SET EQUAL TO ZERO. METRIC 1 USED IN STORING PATTERN 1-B AND IN EACH COMPARISON.

COMPARING PATTERN 1-B WITH STORED PATTERN 1-B

0	-10.3025000	5	4
247.7200000	2457.32780		-246.85000
1	-8.4926440	5	4
204.8781200	1634.78320		-197.04379
2	-6.9969100	5	4
170.5379600	1085.57480		-156.75796
3	-5.7593440	5	4
141.8543900	719.16050		-124.18316

COMPARING PATTERN 2-B WITH STORED PATTERN 1-B

0	-75.1050000	4	3
1525.2400000	85300.43900		-246.85000
1	-62.9606140	4	2
1238.9646000	59200.96400		-197.04392
2	-52.8839510	4	2
1002.1126000	41091.89400		-156.75785
3	-44.3659570	4	2
818.5701700	28515.95200		-124.18294

COMPARING PATTERN 3-B WITH STORED PATTERN 1-B

0	-87.7900000	3	2
2925.2300000	222202.63000		-246.85000
1	-72.2909210	3	2
2380.1344000	149699.96000		-199.56846
2	-59.3990830	3	2
1930.7190000	100443.46000		-160.62130
3	-48.6737120	3	2
1560.2753000	67047.51400		-128.56534

COMPARING PATTERN 4-B WITH STORED PATTERN 1-B

0	-100.2900000	3	2
4060.9800000	334219.31000		-146.85000
1	-81.3190460	3	2
3321.2747000	223883.73000		-132.39390
2	-65.6382200	3	2
2709.8261000	149382.52000		-118.35627
3	-52.6869230	3	2
2204.3515000	99183.44000		-105.00536

COMPARING PATTERN 5-B WITH STORED PATTERN 1-B

0	-75.1050000	8	3
1525.2400000	85300.44100		-246.85000
1	-62.9606140	8	2
1236.4665000	59200.16300		-199.56890
2	-52.8839510	8	2
998.2492200	41089.92700		-160.62144
3	-44.3659570	8	2
814.1879700	28513.30500		-128.56526

COMPARING PATTERN 6-B WITH STORED PATTERN 1-B

0	-87.7900000	9	2
2825.2400000	220951.63000		-146.85000
1	-72.2909210	9	2
2313.0035000	149136.12000		-132.39350
2	-59.3990890	9	2
1888.6773000	100221.42000		-118.35606
3	-48.6739290	9	2
1537.1754000	66979.64200		-105.00536

COMPARING PATTERN 7-B WITH STORED PATTERN 1-B

0	-100.2900000	9	2
3360.9900000	272961.56000		553.15000
1	-81.3190460	9	2
2749.4630000	183007.50000		439.46226
2	-65.6302570	9	2
2243.5383000	122190.30000		348.15552
3	-52.6679070	9	2
1824.9694000	81168.19400		274.83793

COMPARING PATTERN 8-B WITH STORED PATTERN 1-B

0	-75.1050000	4	8
1215.0300000	59757.94200		-246.85000
1	-63.1545560	4	8
990.5266900	41533.58900		-198.62197
2	-53.0857930	4	8
806.8124200	28877.66600		-159.21249
3	-44.5935040	4	8
657.6654800	20085.36700		-127.02096

COMPARING PATTERN 9-B WITH STORED PATTERN 1-B

0	-100.2900000	3	9
1995.6450000	134429.29000		-109.35000
1	-82.8971710	3	9
1643.7889000	92097.39000		-93.00016
2	-68.3478650	3	9
1350.9830000	62908.24400		-78.83496
3	-56.1751480	3	9
1107.8030000	42810.34900		-66.58643

COMPARING PATTERN 10-B WITH STORED PATTERN 1-B

0	-100.2175000	3	7
2684.5400000	195685.98000		-246.85000
1	-81.8774800	9	4
2193.8133000	132159.58000		-198.62194
2	-66.6356610	9	4
1787.9548000	88937.93900		-159.23645
3	-53.9749060	9	4
1452.4537000	59593.54100		-127.08141

COMPARING PATTERN 11-B WITH STORED PATTERN 1-B

0	-100.2150000	3	5
2663.9400000	186622.25000		-246.85000
1	-82.5058520	9	5
2182.9370000	125649.21000		-197.04388
2	-67.7656200	9	5
1784.8741000	84318.52800		-156.75791
3	-55.4956350	9	5
1454.9462000	56362.18800		-124.18305

COMPARING PATTERN 12-B WITH STORED PATTERN 1-B

0	-75.1050000	4	3
1215.0300000	59757.94000		-246.85000
1	-63.1545560	4	3
990.5266700	41533.58700		-198.62198
2	-53.0857930	4	3
806.8124000	28877.66800		-159.21246
3	-44.5935040	4	3
657.6654500	20085.36600		-127.02092

COMPARING PATTERN 13-B WITH STORED PATTERN 1-B

0	-100.2900000	3	2
1995.6450000	134429.29000		-109.35000
1	-82.8971710	3	2
1643.7888000	92097.38600		-93.00014
2	-68.3478650	3	2
1350.9830000	62908.24100		-78.83497
3	-56.1751480	3	2
1107.8032000	42810.34800		-66.58641

COMPARING PATTERN 14-B WITH STORED PATTERN 1-B

0	-100.2175000	9	4
2663.8600000	195686.06000		-246.85000
1	-81.8774800	9	4
2173.1067000	132156.02000		-198.62196
2	-66.6436300	9	4
1769.6046000	88938.41600		-159.23636
3	-53.9947460	9	4
1439.3604000	59599.62000		-127.08142

COMPARING PATTERN 15-B WITH STORED PATTERN 1-B

0	64.7725000	5	3
725.6700000	35671.43900		553.15000
1	54.8673930	5	2
593.7562500	25137.25300		441.98737
2	46.4547990	5	2
491.2423000	17732.08300		352.01941
3	39.2903590	5	2
415.7713200	12514.82400		279.22194

COMPARING PATTERN 16-B WITH STORED PATTERN 1-B

0	64.7725000	5	3
1360.5900000	71385.56700		1353.15000
1	54.5517680	5	2
1097.3899000	49217.11800		1081.01860
2	45.9638760	5	2
881.9667700	34078.96500		860.73279
3	38.7242390	5	2
705.6788400	23699.80800		682.47288

COMPARING PATTERN 17-B WITH STORED PATTERN 1-B

0	-75.1050000	4	3
1047.2900000	52086.31300		-1046.85000
1	-62.9606140	4	2
845.0372900	35610.47400		-836.07500
2	-52.8919200	4	2
680.2633900	24368.31800		-665.47139
3	-44.3851920	4	2
545.4227600	16684.28400		-527.43413

COMPARING PATTERN 18-B WITH STORED PATTERN 1-B

0	-75.1050000	4	3
1846.8600000	101715.29000		-1846.85000
1	-62.9606140	4	2
1482.6974000	69586.97600		-1477.63060
2	-52.8919200	4	2
1186.0622000	47654.42600		-1178.11180
3	-44.3849910	4	2
944.4485400	32653.78000		-935.22135

COMPARING PATTERN 19-B WITH STORED PATTERN 1-B

0	-87.7900000	3	2
2646.8500000	179496.51000		-2646.85000
1	-72.2909210	3	2
2119.1856000	120260.70000		-2119.18560
2	-59.4070530	3	2
1690.7514000	80433.72300		-1690.75140
3	-48.6927470	3	2
1343.0076000	53664.31400		-1343.00760

COMPARING PATTERN 20-B WITH STORED PATTERN 1-B

0	-87.7900000	3	2
3346.8500000	250626.75000		-3346.85000
1	-72.2909210	3	2
2691.0420000	170371.33000		-2691.04200
2	-59.4070590	9	2
2157.2630000	112992.86000		-2157.26300
3	-48.6929650	9	2
1722.8527000	74609.64200		-1722.85270

STORING PATTERN 1-C WITH METRIC 1

0	-100.0000000	5	5
1600.0000000	126250.00000		-1600.00000
1	-80.4312500	5	5
1291.9493000	83607.22900		-1276.79990
2	-64.4303750	5	5
1039.6325000	55473.68000		-1015.55390
3	-51.3550660	5	5
833.0155300	36584.89500		-804.46277
4	-40.6782070	5	5
663.8711000	24015.83700		-633.94417

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 5                     -31.9671940        5        5
 527.9223200            15672.77900           -496.25565
 6                     -25.5785250        4        5
 429.4896700            10153.04900           -385.12450
 7                     -20.5322150        4        5
 351.8105800            6517.11060            -295.47272
 8                     -16.7330250        4        4
 291.2102300            4135.83800            -223.19013
 9                     -13.7058740        4        4
 239.5104400            2588.41930            -164.95010
 10                    -11.1539660        4        4
 195.3814700            1593.24840            -118.06115
 11                    -8.9987690         4        7
 158.1246600            962.41005              -80.34547
 12                    -7.1752847         4        4
 127.0239500            570.57816              -50.04165
 13                    -5.6296510         4        7
 100.4366100            334.37819              -25.72490
 14                    -4.3171880         4        7
 77.6751510             198.50344               -6.24327
 15                    -3.2007690         4        4
 66.1597750             126.40696               9.33464
 16                    -2.2495026         4        4
 56.0025430             94.06272               21.76176
```

PRINT ØF SF ARRAY FØLLØWS

.00	.00	.03	-.08	-.04	-.04	-.08	.03	.00	.00
.00	.05	-.28	.62	.28	.28	.62	-.28	.05	.00
.03	-.28	1.34	-2.40	-.81	-.81	-2.40	1.34	-.28	.03
-.08	.62	-2.40	-41.37	-44.30	-44.30	-41.37	-2.40	.62	-.08
-.04	.28	-.81	-44.30	-45.35	-45.35	-44.30	-.81	.28	-.04
-.04	.28	-.81	-44.30	-45.35	-45.35	-44.30	-.81	.28	-.04
-.08	.62	-2.40	-41.37	-44.30	-44.30	-41.37	-2.40	.62	-.08
.03	-.28	1.34	-2.40	-.81	-.81	-2.40	1.34	-.28	.03
.00	.05	-.28	.62	.28	.28	.62	-.28	.05	.00
.00	.00	.03	-.08	-.04	-.04	-.08	.03	.00	.00

PUNCH ØF PRINTED SF ARRAY FØLLØWS
PRINT ØF SS ARRAY FØLLØWS

.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	-.01	.05	.03	.03	.05	-.01	.00	.00
.00	-.01	.12	-.47	-.33	-.33	-.47	.12	-.01	.00
.00	.05	-.47	-5.00	-5.53	-5.53	-5.00	-.47	.05	.00
.00	.03	-.33	-5.53	-5.91	-5.91	-5.53	-.33	.03	.00
.00	.03	-.33	-5.53	-5.91	-5.91	-5.53	-.33	.03	.00
.00	.05	-.47	-5.00	-5.53	-5.53	-5.00	-.47	.05	.00
.00	-.01	.12	-.47	-.33	-.33	-.47	.12	-.01	.00
.00	.00	-.01	.05	.03	.03	.05	-.01	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

PUNCH ØF PRINTED SS ARRAY FØLLØWS
PRINT ØF DE ARRAY FØLLØWS

.00	-.01	.06	-.07	.00	.00	-.07	.06	-.01	.00
-.01	.09	-.25	.06	-.27	-.27	.06	-.25	.09	-.01
.06	-.25	.12	1.73	2.04	2.04	1.73	.12	-.25	.06
-.07	.06	1.73	-2.24	-.49	-.49	-2.24	1.73	.06	-.07
.00	-.27	2.04	-.49	1.82	1.82	-.49	2.04	-.27	.00
.00	-.27	2.04	-.49	1.82	1.82	-.49	2.04	-.27	.00
-.07	.06	1.73	-2.24	-.49	-.49	-2.24	1.73	.06	-.07
.06	-.25	.12	1.73	2.04	2.04	1.73	.12	-.25	.06
-.01	.09	-.25	.06	-.27	-.27	.06	-.25	.09	-.01
.00	-.01	.06	-.07	.00	.00	-.07	.06	-.01	.00

```
 17                      2.4741580        5        6
 51.6688430              85.78338              31.64632
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THE FOLLOWING SETS OF PATTERN COMPARISON DATA WERE OBTAINED BY USING THE STORED SF ARRAY OF PATTERN 1-C AS THE SS ARRAY DURING THE COMPARISON. THE SF ARRAY IS SET EQUAL TO ZERO. METRIC 1 USED IN STORING PATTERN 1-C AND IN EACH COMPARISON.

COMPARING PATTERN 2-C WITH STORED PATTERN 1-C

0	-74.8325000	3	5
805.0100000	37271.35100		-165.60000
1	-62.9520660	3	5
660.5240900	26155.32600		-133.49203
2	-52.8849570	3	5
544.2503800	18387.48100		-107.22161

COMPARING PATTERN 1-C WITH STORED PATTERN 1-C

0	-10.2800000	4	4
168.2000000	1649.37280		-165.60000
1	-8.7222020	4	7
142.7227600	1121.76880		-132.22961

COMPARING PATTERN 3-C WITH STORED PATTERN 1-C

0	-87.7925000	2	5
1474.7400000	97960.22700		-115.60000
1	-72.2929140	2	5
1203.6468000	66686.10400		-99.90457

COMPARING PATTERN 4-C WITH STORED PATTERN 1-C

0	-74.8325000	8	5
805.0100000	37271.35500		-165.60000
1	-62.9520660	8	5
660.5241300	26155.32900		-133.49205

COMPARING PATTERN 5-C WITH STORED PATTERN 1-C

0	-87.7925000	9	5
1474.7400000	97960.23200		-115.60000
1	-72.2929140	9	5
1203.6478000	66686.11200		-99.90457

COMPARING PATTERN 6-C WITH STORED PATTERN 1-C

0	-74.8325000	5	3
805.0100000	37271.35700		-165.60000
1	-62.9520660	5	3
660.5241500	26155.33500		-133.49207

COMPARING PATTERN 7-C WITH STORED PATTERN 1-C

0	-87.7925000	5	2
1474.7400000	97960.23200		-115.60000
1	-72.2929140	5	2
1203.6469000	66686.11000		-99.90459

COMPARING PATTERN 8-C WITH STORED PATTERN 1-C

0	-74.8825000	5	8
805.0100000	37271.35800		-165.60000
1	-62.9520660	5	8
660.5241600	26155.33500		-133.49207

COMPARING PATTERN 9-C WITH STORED PATTERN 1-C

0	-87.7925000	5	9
1474.7400000	97960.23400		-115.60000
1	-72.2929140	5	9
1203.6469000	66686.11200		-99.90460

COMPARING PATTERN 10-C WITH STORED PATTERN 1-C

0	-75.0450000	3	7
1264.3300000	67682.35400		-165.60000
1	-62.9923640	3	8
1036.9625000	47369.29500		-134.75456

COMPARING PATTERN 11-C WITH STORED PATTERN 1-C

0	-100.0000000	3	8
2103.8200000	152804.61000		-65.60000
1	-81.0486140	3	8
1722.8172000	103410.96000		-66.94831

COMPARING PATTERN 12-C WITH STORED PATTERN 1-C

0	-75.0450000	7	3
1264.3300000	67682.35700		-165.60000
1	-62.9923640	8	3
1036.9628000	47369.29900		-134.75456

COMPARING PATTERN 13-C WITH STORED PATTERN 1-C

0	-100.0000000	8	3
2103.8200000	152804.67000		-65.60000
1	-81.0486140	8	3
1722.8183000	103411.04000		-66.94831

COMPARING PATTERN 14-C WITH STORED PATTERN 1-C

0	64.7575000	4	5
1042.7600000	53739.85500		1034.40000
1	54.2840500	4	4
847.6561100	37045.83600		825.37041

COMPARING PATTERN 15-C WITH STORED PATTERN 1-C

0	-75.0450000	3	4
2166.3200000	125771.29000		-2165.60000
1	-62.9923640	3	3
1741.6012000	85761.09300		-1735.80320

COMPARING PATTERN 16-C WITH STORED PATTERN 1-C

0	-100.0000000	3	3
4565.6000000	378829.72000		-4565.60000
1	-81.0486140	3	3
3701.5022000	251791.38000		-3701.50220

COMPARING PATTERN 17-C WITH STORED PATTERN 1-C

0	90.1750000	6	5
1342.7600000	85282.23200		1334.40000
1	73.243[illegible]350	6	5
1087.0550000	56889.46700		1064.77060

COMPARING PATTERN 1-C WITH STORED PATTERN 1-C USING METRIC 5

0	-15.0000000	5	5
270.1200000	3285.90900		-247.64000
1	-11.1560750	4	5
205.5072900	1801.46880		-172.62121

COMPARING PATTERN 3-C WITH STORED PATTERN 1-C USING METRIC 5

0	-125.5750000	3	5
2192.6200000	195415.22000		-147.64000
1	-93.6965500	2	5
1607.9797000	108667.84000		-123.12132

COMPARING PATTERN 4-C WITH STORED PATTERN 1-C USING METRIC 5

0	-100.5750000	8	5
1214.0600000	68741.89500		-247.64000
1	-73.1376060	8	5
899.4278900	39995.04500		-177.67122

COMPARING PATTERN 2-C WITH STORED PATTERN 1-C USING METRIC 2

0	-76.3775000	3	5
1010.5900000	45168.60900		-206.62000
1	-62.0024250	3	5
792.8802400	28804.94200		-159.50983

COMPARING PATTERN 2-C WITH STORED PATTERN 1-C USING METRIC 3

0	-99.0800000	3	5
1014.9000000	60565.60600		-206.62000
1	-79.2795240	3	6
788.7462400	38326.73600		-155.72224

COMPARING PATTERN 3-C WITH STORED PATTERN 1-C USING METRIC 2

0	-101.3775000	3	5
1805.6400000	134701.10000		-106.62000
1	-79.4274390	3	5
1404.8701000	83754.91300		-94.85986
2	-62.1156180	2	5
1095.1132000	52032.70000		-83.61499

COMPARING PATTERN 3-C WITH STORED PATTERN 1-C USING METRIC 3

0	-113.0175000	2	5
1864.9300000	151759.33000		-156.62000
1	-88.3443450	2	5
1442.0625000	92415.03400		-127.18483
2	-68.8552490	2	5
1123.6107000	56139.67500		-102.80793

COMPARING PATTERN 4-C WITH PATTERN 1-C USING METRIC 2

0	-76.3775000	8	5
1010.5900000	45168.61200		-206.62000
1	-62.0024250	8	5
792.8802400	28804.94200		-159.50983

COMPARING PATTERN 4-C WITH PATTERN 1-C USING METRIC 3

0	-99.0800000	8	5
1014.9000000	60565.61000		-206.62000
1	-79.2795260	8	5
788.7462400	38326.74200		-155.72224

COMPARING PATTERN 5-C WITH PATTERN 1-C USING METRIC 2

0	-101.3775000	8	5
1305.3400000	134701.21000		-106.62000
1	-79.4274380	8	5
1404.3707000	33754.92100		-94.85989

COMPARING PATTERN 5-C WITH PATTERN 1-C USING METRIC 3

0	-113.0175000	9	5
1364.0300000	151759.44000		-156.62000
1	-83.3443400	9	5
1442.0321000	32415.04000		-127.18480

COMPARIL.G PATTERN 2-C WITH PATTERN 1-C USING METRIC 5

0	-100.5750000	3	5
1214.0600000	68741.89100		-247.64000
1	-78.1376150	3	5
399.4279200	39995.04200		-177.67123
2	-60.9514330	3	5
681.5403800	23642.50200		-126.62112

COMPARING PATTERN 1-C WITH PATTERN 1-C USING METRIC 4

0	-8.6300000	4	4
139.4000000	707.16840		-83.56000
1	-7.7533700	4	4
125.3206000	571.53406		-75.12044

COMPARING PATTERN 2-C WITH PATTERN 1-C USING METRIC 4

0	-49.1900000	3	5
469.2400000	17199.16100		-83.56000
1	-44.2218100	3	5
421.8467600	13900.37700		-75.12044

COMPARING PATTERN 3-C WITH PATTERN 1-C USING METRIC 4

0	-50.6200000	2	4
827.8400000	35309.15000		-83.56000
1	-45.5073800	2	4
744.2231600	28536.88500		-75.12044

COMPARING PATTERN 4-C WITH PATTERN 1-C USING METRIC 4

0	-49.1900000	8	5
469.2400000	17199.16300		-83.56000
1	-44.2218100	8	5
421.8467600	13900.37900		-75.12044

COMPARING PATTERN 5-C WITH PATTERN 1-C USING METRIC 4

0	-50.6200000	9	4
327.8400000	35309.15700		-83.56000
1	-45.5073800	9	4
744.2281600	28536.89100		-75.12044

COMPARING PATTERN 18-C WITH STORED PATTERN 1-C USING METRIC 1

0	-49.8325000	3	6
384.9900000	10314.24400		-165.60000
1	-43.9489410	3	6
331.2192300	7841.36290		-132.86085

COMPARING PATTERN 19-C WITH STORED PATTERN 1-C USING METRIC 1

0	-49.8825000	3	5
601.7800000	18979.11500		-165.60000
1	-43.9489410	3	5
525.2548200	14664.08300		-133.49209

COMPARING PATTERN 20-C WITH STORED PATTERN 1-C USING METRIC 1

0	-62.3825000	3	5
602.7200000	23979.10600		-165.60000
1	-53.9239410	3	5
517.1675100	18022.02400		-133.49207

COMPARING PATTERN 21-C WITH STORED PATTERN 1-C USING METRIC 1

0	-62.3825000	3	5
966.3200000	38647.86100		-965.60000
1	-53.2926910	3	5
789.4223400	27137.99000		-773.15447

COMPARING PATTERN 22-C WITH STORED PATTERN 1-C USING METRIC 1

0	65.1750000	5	5
325.7200000	17455.86200		234.40000
1	55.1869850	5	5
269.3033400	12536.39400		186.97039

COMPARING PATTERN 23-C WITH STORED PATTERN 1-C USING METRIC 1

0	-75.0450000	3	4
2287.7200000	139077.79000		-1765.60000
1	-62.9923640	3	3
1868.9469000	96690.35600		-1416.60390

COMPARING PATTERN 24-C WITH STORED PATTERN 1-C USING METRIC 1

```
0                      90.1750000        5        5
2123.8400000          122282.77000            -565.60000
1                      73.8744850        5        5
1783.4882000           87486.71800            -456.47961
```

STORING PATTERN 1-D USING METRIC 1

```
0                 -75.0000000       6        3
1875.0000000      103437.50000          -1875.00000
1                 -63.6375000       8        2
1527.1801000       71554.22100          -1513.29310
2                 -53.9875250       8        2
1240.8355000       49683.63000          -1218.48360
3                 -45.7777230       8        2
1005.1438000       34632.49600           -978.16541
4                 -38.7808940       8        2
812.0890900        24238.96400           -782.21843
5                 -32.8072800       8        2
659.8041300        17036.07100           -622.42403
6                 -27.6982120       8        2
543.9840500        12025.96600           -492.08947
7                 -23.3208510       8        2
454.4441900         8528.03590           -385.76653
```

```
8                 -19.5638370       8        2
395.2107000         6076.70940           -299.02004
9                 -16.3336910       8        2
353.8073100         4352.53800           -228.23857
10                -13.5518380       8        2
317.0074800         3135.58280           -170.48075
11                -11.1521270       8        2
283.1655700         2273.87790           -123.35095
12                 -9.1207400       3        7
252.9405600         1662.02640            -84.89712
13                 -7.7058402       3        4
225.4970600         1226.63700            -53.52859
14                 -6.4744520       3        7
200.3324400          916.38781            -27.94868
15                  5.6016670       5        4
177.2719400          695.23644             -7.10017
16                  5.6812710       5        4
156.1504100          537.75716              9.87932
PRINT ØF SF ARRAY FØLLØWS
    .00     .10    -.66    2.42   -2.87   -2.87    2.42    -.66     .10     .00
    .04    -.40    2.35   -7.16  -38.60  -38.60   -7.16    2.35    -.40     .04
   -.03     .35   -2.08  -38.79   -4.72   -4.72  -38.79   -2.08     .35    -.03
   -.36    2.16   -6.52  -37.98   -1.34   -1.34  -37.98   -6.52    2.16    -.36
    .38   -2.43  -36.99   -9.19     .63     .63   -9.19  -36.99   -2.43     .38
   2.10   -5.47  -42.31  -41.07  -43.16  -43.16  -41.07  -42.31   -5.47    2.10
  -3.25  -37.59   -5.02    -.84   -1.42   -1.42    -.84   -5.02  -37.59   -3.25
   -.61  -44.80    -.13     .63     .34     .34     .63    -.13  -44.80    -.61
  -2.98  -38.80   -3.15     .66    -.14    -.14     .66   -3.15  -33.80   -2.98
   1.55   -3.64    1.60    -.31     .04     .04    -.31    1.60   -3.64    1.55
```

PUNCH ØF PRINTED SF ARRAY FØLLØWS
PRINT ØF SS ARRAY FØLLØWS

.00	.00	-.03	.21	-.52	-.52	.21	-.03	.00	.00
.00	-.02	.20	-1.18	-4.48	-4.48	-1.18	.20	-.02	.00
.00	.04	-.45	-4.49	-.97	-.97	-4.49	-.45	.04	.00
-.02	.19	-1.12	-4.42	-.36	-.36	-4.42	-1.12	.19	-.02
.04	-.47	-4.34	-1.64	-.20	-.20	-1.64	-4.34	-.47	.04
.19	-1.04	-5.08	-4.98	-5.15	-5.15	-4.98	-5.08	-1.04	.19
-.54	-4.40	-.98	-.33	-.39	-.39	-.33	-.98	-4.40	-.54
-.34	-5.30	-.29	.08	.04	.04	.08	-.29	-5.30	-.34
-.53	-4.52	-.54	.06	.00	.00	.06	-.54	-4.52	-.53
.13	-.59	.14	-.01	.00	.00	-.01	.14	-.59	.13

PUNCH ØF PRINTED SS ARRAY FØLLØWS
PRINT ØF DE ARRAY FØLLØWS

17	5.6897410	5	4
136.8127400	425.93198		23.69334

COMPARING PATTERN 1-D WITH STORED PATTERN 1-D USING METRIC 4

0	-13.0100000	5	3
314.0800000	2707.34920		-114.04000
1	-11.6959900	5	3
282.3579200	2188.08040		-102.52196

COMPARING PATTERN 2-D WITH STORED PATTERN 1-D USING METRIC 4

0	-49.8700000	8	8
1009.7800000	37492.32400		-114.04000
1	-44.8331300	8	8
907.7922200	30301.33000		-102.52196

COMPARING PATTERN 3-D WITH STORED PATTERN 1-D USING METRIC 4

0	-52.3500000	2	3
1215.2400000	48126.32300		-64.04000
1	-47.0626500	2	3
1092.5004000	38895.73600		-57.57196

COMPARING PATTERN 4-D WITH STORED PATTERN 1-D USING METRIC 4

0	-49.8700000	8	8
768.4400000	25425.33700		135.96000
1	-44.8331300	8	8
690.8275600	20548.77900		122.22804

COMPARING PATTERN 5-D WITH STORED PATTERN 1-D USING METRIC 4

0	-50.6300000	5	5
799.5600000	27107.33100		-714.04000
1	-45.5163700	5	5
718.8044400	21908.16700		-641.92196

COMPARING PATTERN 6-D WITH STORED PATTERN 1-D USING METRIC 4

0	-52.3500000	2	8
1182.9600000	46829.32500		-64.04000
1	-47.0626500	2	8
1063.4807000	37847.49900		-57.57196

COMPARING PATTERN 7-D WITH STORED PATTERN 1-D USING METRIC 4

0	-50.6600000	9	4
993.3000000	36860.33000		35.96000
1	-45.5433400	9	4
892.9767000	29790.55100		32.32804

COMPARING PATTERN 8-D WITH STORED PATTERN 1-D USING METRIC 4

0	-52.3500000	2	3
1397.0200000	57344.32600		-214.04000
1	-47.0626500	2	3
1255.9207000	46345.73800		-192.42196

COMPARING PATTERN 9-D WITH STORED PATTERN 1-D USING METRIC 4

0	-52.3500000	2	3
1293.5000000	52042.32600		-114.04000
1	-47.0626500	2	3
1162.8563000	42060.65700		-102.52196

COMPARING PATTERN 10-D WITH STORED PATTERN 1-D USING METRIC 4

0	-52.3500000	2	3
1084.2200000	41684.32300		85.96000
1	-47.0626500	2	3
974.7137800	33689.30700		77.27804

COMPARING PATTERN 11-D WITH STORED PATTERN 1-D USING METRIC 4

0	-52.3500000	2	3
1192.7200000	47109.32300		-114.04000
1	-47.0626500	2	3
1072.2552000	38073.79900		-102.52196

COMPARING PATTERN 12-D WITH STORED PATTERN 1-D USING METRIC 4

0	-52.3500000	2	3
1381.7600000	56389.32300		85.96000
1	-47.0626500	2	3
1242.2016000	45573.90300		77.27804

COMPARING PATTERN 13-D WITH STORED PATTERN 1-D USING METRIC 4

0	-52.3500000	2	3
1385.0400000	56616.32300		-14.04000
1	-47.0626500	2	3
1245.1503000	45757.36600		-12.62196

COMPARING PATTERN 14-D WITH STORED PATTERN 1-D USING METRIC 4

0	-52.3500000	2	3
1489.5800000	61906.32300		-214.04000
1	-47.0626500	2	3
1339.1317000	50032.74900		-192.42196

COMPARING PATTERN 15-D WITH STORED PATTERN 1-D USING METRIC 4

0	-50.6300000	5	5
1220.8800000	48173.32300		85.96000
1	-45.5163700	5	5
1097.5708000	38933.72100		77.27804

COMPARING PATTERN 16-D WITH STORED PATTERN 1-D USING METRIC 4

0	-52.3500000	2	8
1213.8200000	48026.32300		335.96000
1	-47.0626500	2	8
1091.2239000	38814.91900		302.02804

COMPARING PATTERN 17-D WITH STORED PATTERN 1-D USING METRIC 4

0	-52.3500000	2	3
1443.8600000	59861.32200		-164.04000
1	-47.0626500	2	3
1298.0298000	48379.97300		-147.47196

Vita

William L. Harrison was born on 2 July 1929 in Janesville, Wisconsin, the son of Vern P. Harrison and Ruby M. Harrison. After graduating in 1947 from Fairfield Community High School, Fairfield, Illinois, he enlisted in the U.S. Navy. In 1951 he received an appointment to the U.S. Naval Academy, from which he was graduated in June, 1955, with the degree of Bachelor of Science. After accepting a commission as Lieutenant in the U.S. Air Force, he underwent flight training and then performed flying duties in the Air Defense Command and the Pacific Air Forces prior to entering the Air Force Institute of Technology in February, 1962.

This thesis was typed by Mary Marlene Harrison

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