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MODELING OF EXPLORATIVE PROCEDURES FOR REMOTE OBJECT IDENTIFICATION

by

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# Modeling of Explorative Procedures for Remote Object Identification

by

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# ABSTRACT

This work addresses the issue of how humans manually explore remote objects using a telemanipulator. An understanding of how conceptual models are constructed is necessary since it will ultimately determine the efficiency of ROV'S using telepresence. The representation of human search models is achieved by using the proprioceptive component of the haptic sensory system and the simulated foveal component of the visual system. Eventually it will allow multiple applications in remote sensing and superposition of sensory channels. The use of a force reflecting telemanipulator and computer simulated visual foveal component are the tools which offer the possibility of reconstructing these search patterns observed in different subjects under controlled laboratory conditions. The correlation between the two search strategies is explored and represented in code circles and strings which demonstrates the sequential nature of the two types of probing, as opposed of saccadic response in full vision.

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# I. INTRODUCTION

## A. GENERAL

In order to adapt ourselves and respond to the instantaneous and continuous changes of every form of energy in the surrounding environment, humans appeal to the gathering of information through the different sensory systems and channels. This human environment is built up of all the animate and inanimate animals, plants and objects which are permanently providing stimulus for the sensory receptors. Since early ages, these receptors have been regarded as the five well known senses: vision, hearing, smelling, tasting and touching; acting as transmitters of signals through the nerve fibers and into the brain, in which all the information was processed enabling the person to respond in the presence of his needs. This accepted belief posed the human as passive subjects in obtaining consciousness of their world. But in relatively new times, the word sense has acquired two different meanings: to have a sensation, which can be defined as a subjective personal feeling upon a stimulation such as when watching a drawing or hearing music; or as the action of detection and exploration of the world by actively searching and looking for updated information, which is defined as perception. This latter aspect is what we are interested in focusing our attention in the present research and specifically to the haptic proprioceptive system which will further be analyzed. In this new dimension, the subject is not passive but capable of actively exploring and looking for actualized information in his awareness of his dynamical environment. This is what allows humans to avoid threats and perils, the enrichment of wisdom and development, the consciousness and belief of its own world.

## B. HUMAN RECEPTORS AND THEIR STIMULATION

### 1. Receptors

Perception of the outer, the real sensible and tangible world, is not a simple process. It is a high level one in which the brain realizes about the enclosing stimulations with the participation of the entire body. It is a psychological function which enables us to receive and process information about our environment. And is not a simple one since perception is not passive but active and constructive, exploratory and performatory. This way, in the process of increasing our knowledge of the world that surrounds us, the brain makes use of a universe of stored experiences which are continuously updated and refined. The experiences are assimilated and conveyed into the individuals mental space through processes of perception. This is why we can recognize objects as themselves even if we see them from different angles or distances; an airplane remains taken as an airplane whether seen flying or grounded. For these accomplishments humans have been provided by nature with different types of receptors which allow the incoming stimuli be perceived and learned.

We find different categories in human receptors: The lowest *anatomical* unit that can respond to the different sources of stimulations are the unit cells, e.g.: photosensitive rods and cones of the retina. These cells are connected to the different branches of nerve fibers that are spread all over the body and from here to the central nervous system. They are considered as transducers, capable of converting energy changes into signals, that modulate series of impulses when energy is applied to them and that modify the inputs as a function of the change and interrelation of energy. A change in the environment implies a change of energy, and when the structure of the receptor is changed either by mechanical work and thus suffering deformation or by the effects of electromagnetic radiation or by a chemical interaction, the effect over the receptor is an alteration in its permeability to ions which leads to the generation of an electrical current or a voltage change. This variation in voltage within the neurons, give rise to the succession of impulses by which the change perceived in the environment is transmitted to the nervous system and into the brain. At this stage, we pass from the energy domain to that of signals or messages having symbolic values. Physiologists classify three kinds of receptor cells or transducers which corresponds to the general forms of energies: 1) mechanoreceptor, 2) photoreceptor and 3) chemoreceptor. These unit cells are in their nature passive mechanisms but not all receptors imply this quality. The case of the eye is an example of an active and explorative organ that configures and adapts its internal arrangements and external orientation in order to obtain the maximum possible stimulations. These active type of receptors must have the ability to move and therefore must be supported by muscles and nerves connected directly to the central nervous systems. There are no distinct nerves for each mode of sensation, rather they exist in bundles which have mixed and interdependent functions. Humans have also developed movable and adjustable limbs and sense organs so they are able to treat the gathering of stimulus by using motor and sensor organs. Motor organs are defined as those which are based upon body activity involving muscular processes or consciousness of movement. This sense is dependant on receptors which are stimulated by tension or relaxation of muscles or movements of the parts of the body and offer spatial information about them. The so-called sensory organs are those which account for mechanisms involving neural activity when under the presence of energy stimulus that excite the receptor. Those sensor organs respond to defined thresholds which is the magnitude of stimulus intensity required at which a transition occurs from no sensation to sensation. The organs give a basis for the conformation of systems which allow the human to perform more complex explorative tasks handling several variables at a time, e.g. gravity, equilibrium, light, etc. This in turn implies that the stimulus for each hierarchy are different in their level as their complexity grows.

> The eye with its attached muscles is a system of higher order; it is stabilized in the head relative to the environment with the help of the inner ear, and it can scan the environment. The two eyes together make a dual system of still higher order; the eyes converge for near objects and diverge for far ones. (Gibson, 1966, p. 42)

When the systems act as active ones and their function is to pick up information instead of passive conductors of sensations, they are considered as perceptual systems. They are then, instruments of obtaining knowledge, not purely channels of feelings or sensations. Perceptual systems are classified by their modes of activity and not of qualitative perceptions since they have the potential to pickup information without limits except those imposed by their environmental stimulus. These systems are not mutually exclusive and often overlap their gathering of information. They may act in a redundant manner picking up the same information as others systems or share information between them. Thus, if a person were imposed under the stimulation of rain, different systems would pick up the same information at the same time but through the use of different perceptual channels. The visual, auditory and haptic would overlap while the tasting and maybe the smelling system ignore it. The feeling and the perception can occur simultaneously, they are not mutually exclusive but perception can occur without the occurrence of an intellectual process and not in all perception processes do sensations occur. Perception can occur because of stimulation of passive receptors which resonate to their corresponding form of energy and also due to the perceptual systems which are active searchers, continuous seekers of stimulus energy and information. These perceptual systems act in an interrelated basis. The human not only receives stimulation from external sources of the environment but also by its internal organs which give sense of awareness of movement. Muscles and joints in mayor limbs act as feedback stimulus providing spatial and temporal information.

Sensory systems are comprised of all the mechanisms by which the nervous system responds to physical energy in the environment in order to produce sensory experience. This systems fall into three broad categories: Exteroceptors; which are concerned with stimuli which originates outside of the body and provide information about events of the external world, e.g. olfactory, gustatory, visual, auditory, and somatic senses which furnish the smell, sight, auditive and feeling stimuli of contact with the body surface. Proprioceptors; sensations of movement stimulated by the action of the body and provides information about the activity and position of the body and limbs. Under this category falls the vestibular system which is concerned about the static position of head and its movements affected by gravity, information that is proportioned by the inner ear, and the kinesthetic system which is concerned with sensations originated from the muscles, tendons and joints and which provide information about the limbs and body. Interoreceptors; which are those nerve endings in the visceral organs which are concerned with sensations of pain, pressure and temperature of these internal organs.

It should be noticed that, receptors are all interrelated. Eyes and ears can record external events but at the same time movements and actions of the same individual, conversely the joints and muscles can record imposed movements over the body or movements of the individual's initiative. With their interactive information, the individual orients and survives in his environment.

## 2. Feedback

The sensory and perceptual systems act as adjustable extensions, with varying spatial and temporal effects, which can be repositioned or reoriented in order to obtain optimal discernment accordingly to the external stimuli being explored or perceived. The effect of the stimuli gives rise to what physiologists define as sensory motor or neural arc, which is any connected series of neurons that extend from the receptors to the effectors and are capable of transmitting an impulse of excitation. So given a stimulus, a response can be executed. This process includes paths at all levels of hierarchy, so it is the participation of inputs and outputs which are constantly updating the individuals state of qualitative information and thus allowing him resonate with the incoming sensory stimuli and therefore perceive his environmental activity. It is a feed back or self regulating system that uses the gathered information from one event or stimuli to control related subsequent events and therefore obtain the maximum possible knowledge of his purposive actions. But action produced stimulation is inherent to the individuals own movements and performance so instead of being only and external inflow of stimuli it also feeds back information based upon output of the individuals activity. To be able to differentiate between these two, one theory suggests that the memory plays a role in this identification by storing copies of commands sent by the brain for an specific movement. When the input of the receptors reaches the brain through the neural arcs, it is compared to the stored copy in memory, if it matches, the input is identified as a proprioception stimuli and conversely, it will be taken as a feeding from the environment.

> Roughly speaking, when a muscle is stretched, a reflex circle arises so as to contract the muscle and compensate for the pull. The delicate play of this tonus in all muscles is what enables the animal to keep it's balance. Equilibrium is a process of continuous compensation. (Gibson, 1966, p. 35)

An experiment developed in the psychology field is evident in its results. The artificial interruption of the dorsal spinal root of the sensory paths incoming from the muscles and joints of a given human limb, show that the limb remains able to move since the output neural paths are still functioning but the limb reacts in an uncontrollable fashion. The interesting result is that if the subject is allowed to use his vision, the movements of the limb can be voluntarily controlled. This proves without doubt the reflex circle or feedback theory and at the same time the important fact that a given perceptual system can be substituted for, or substitute another given perceptual system. This is more evident in the case of haptic and vision but also depends upon the hierarchy of the systems involved. It is also obvious that by the use of conventional words, speech can substitute certain stimuli sources; gestures can also become an equivalent substitution everybody is familiar with the guessing games in which a person by appealing to gestures and mimic, transmits coherent and compressed packages of information to second persons, who are supposed to guess what is wanted. The results are in most cases positive and successful. Other experiments have been carried out such as with the auditory system where a time delay is incorporated in the hearing of a person speaking using electronic means. What is observed is the degradation of the speech ability of the person, proving that the auditory system is one of the main feedback component in the speech mode. In this case, impairment can be overcome by substitution with the successful use of the Tadoma method:

> -- a method of understanding speech in which the listener's fingers and thumb(s) are placed on the cheeks, lips and jaws of the speaker- is proof that the tactual system can process complex spatiotemporal patterns at rates close to those of auditory speech perception. (Klatzky, Lederman & Metzger, 1985, p. 299)

Life is full of examples of handicaps being overcomed by the appropriate substitution of systems. This is obvious in the case of blind people who orient themselves by using on the auditory system and conversely deaf people depending on the visual system for their communication. We have proof of excellent painters and artists who in absence of their upper extremities, use their lower ones or their mouth to hold and control the paintbrushes and crayons. In this way stimulus and perception systems act in an interdependent way to maintain its communication channels for the comprehension of the world, and by feedback optimizing this flow of information.

### 3. Stimuli

To understand the infinite possibilities of stimulation of human receptors we must first analyze the different broad parameters that govern the terrestrial environment. Earth, water and air are the basic elements of our world and are in continuous transformation due to the incessant conversion of energy as the laws of thermodynamics The well known cycle of evaporating water due to radiation energy from the sun, its following condensation as clouds and further precipitation is a simple example.

> All animals, even a single-celled creature like the ameba, respond to contact mechanics, contact chemistry and lightheat. The ameba makes only a few crude responses like approach or avoidance to such energy applications (Jennings, 1906), for the whole animal is all one receptor, while higher animals make more elaborate responses to finer differences. (Gibson, 1966, p. 40)

A stimuli that exerts over a person that is embedded in a natural environment has the following characteristics:

1. A stimulus always has some adjacent order. I has a simultaneous structure or pattern in "space". Even the sharp stick on the skin or the narrow beam of light on the retina yields a border or transition, not a mathematical point. To say that a stimulus has a "pattern" or "form" is an effort to express this fact.

2. A stimulus always has some successive order. It has some structure in "time". At the very least there is a transition at the beginning and another at the end, so that the stimulus is never a mathematical instant. It has sequential structure just as inevitably as it has simultaneous structure.

3. Consequently a stimulus always has some component of non change and some component of change. (Gibson, 1966, p. 40)

So we can derive that stimuli are spatial and temporal and that the transformations as well as the invariant of the stimulation energy are stimuli in themselves. If a person is given a box with objects inside and asked to detect what is in it, he will tend to shake it in order to obtain the desired information. The motion applied to the container could be in a random manner but what the subject would be looking for is not changes in sound or shifting in centers of gravity. What he will concentrate upon is on those invariant parameters that eventually will allow him to guess right, for example, sound produced by metal.

Stimulus can be internal or external, large or small, instantaneous or continuous, constant or variable, located or generalized; it can be any type of energy that activates any of the cells, organs or systems of the human body. Humans are submitted to stimulus energy originating from internal or external sources. We can summarize three basic types of energies: chemical, mechanical and electromagnetic. We find that in our terrestrial environment animals can become the source of any of these energy forms; even electric current as found in seawater creatures like the eel or radiant light as in insects. Several types of stimulus may proceed from the same source and they may be coinciding at the same time, this quality may identify or define the character of the stimulus source. In the animal world we find infinite examples of male and female response to the kind of chemical either one diffuses, or by the types of sounds or mechanical contact each might produce. The kind and intensity of energy may give rise to the evaluation of the quality of the source, if its friendly or enemy, living or inert, moving or stationary. Not all of the possible stimuli sources present in the environment is perceived or recorded, mainly because we focus our attention only on those which provide information of our interest, but the potential stimulus the environment offers is humongous. As humans we are most interested for the purpose of this research in a scale that can be measured by levels within our senses thresholds and particularly mechanical contacts and visual apprehension.

The intensity and frequency of light, sound, odor and touch, are variables of stimulus energy that can be measured. They display values that are continuously changing over space and time, the stimulation of receptors are therefore changing permanently, but humans are able to isolate those invariant that remain in the quality of the object observed or perceived. He can identify a car at high speed, for example, despite its change in position and changes in the intensity of the reflected light, he can perceive the presence of an obstacle, despite the variations of contact force, he can detect the invariant despite the changes in the flux of energy as well as he can detect the changes of this fluxes, the invariant are therefore a measure of information about the perpetual environment. This means that the perception of an object seems to be relatively stable though the energy reaching the sense organs are constantly changing. This phenomenon is known in psychology as object constancy (size and shape). The perception of speed and relative positions of external objects, is built up based on parallel and simultaneous information received over several different neural pathways and interpreted with the aid of previous conclusions of past experiences. This is an appeal to memory as we can infer from the object constancy facts.

We have to differentiate between physical stimulus versus perceived stimulus. The former is also known as objective stimulus and refers to the physical energy of the stimulus at its source. The latter is also known as subjective stimulus and refers to the physical energy that strikes the sensory receptor. In the case of the visual sense for example, the light that impinges over the retina has overcome changes since it was reflected by its source and traveled through the air, which also affects the energy composition, and enter the eyes. Inside the eye, it has to move along the vitreous liquids and different layers of the retina until reaching and exciting the photoreceptor. The interesting phenomenon that leads to the size and shape constancy is that the perceived stimulus tend to correspond not to the subjective stimulus which is the one that has stimulated the receptors, but to the physical stimulus. This can be easily proved by holding a circular figure at an arms length of distance and slowly tilting it, which produces a retinal image of a circle transforming into an ellipse, in despite of this, the perceived figure is not taken as changing in shape but that of a tilting circle or maybe just of a circle. In the case of the perceived size of an object, this depends on the physical size and distance from it, information which is not provided directly by the physical energy that fires the receptors. However, the observer seems to have a variety and considerable quantity of information stored in its memory such as relative sizes of familiar objects; information that supposedly supports the judgement and allows to infer the size and distance separating from the object. The evidence from neurophysiological experiments shows that information about the nature of the stimulus is not necessarily present in the messages originated from the sense organs which have been stimulated. Nervous messages do not contain information about the nature of the process that initiated the sending of the signal. A simple experiment can illustrate this point, if someone stares to the maximum physical angle to the right of the eyes and having them closed tap with the fingertips the extreme outer edge of the left eyelid, he will experience a flash of light in his left eye as if radiant energy had stimulated it. What really has happened is that the receptors in the eye can also be activated by a mechanical pressure or deformation. In most of the cases obviously, these receptors are going to be stimulated by light and in fact, they are located in a place in which are relatively well protected against mechanical deformations, but this is a very graphical example of the absence of human capacity to differentiate the nature of the process relying only on the neural stimuli.

Stimuli interact, they do not remain isolated one from another travelling their course until each localized stimulus produces a separate sensation, so that sensory consciousness represents the addition of all the stimuli but rather the relationship between them is what produce perceptual effects. It is the interaction between them which provide sufficient information interfaces which in the brain as a whole, produces the ability and capacity of humans to operate as perceptual systems that obtain updated knowledge of the world. Stimuli deprivation experiments carried out with humans by isolating them from any type of stimuli, as in isolation chambers, show erratic behavior after certain time under this conditions. It seems that the brain is always spontaneously active and this activity is normally under control of sensory signals. When they are deprived, the person losses communication with its world and the brain, instead of processing perception of the world, can produce hallucinations or fantasies which dominates the person. The overall activity of the stimuli, cells, organs and systems is what therefore, maintains our ties with events and the world.

## C. VISUAL SYSTEM

The high degree of specialized structure of every component of the visual system places it as one of the most important in the human body enhancing its value in the individuals requirements for survival. We will here review the human visual system in a very general form focusing specially on those characteristics that affects the modes of perception.

Each eyeball is equipped with six muscles which holds them in the desired position in their orbits rotating accordingly for following moving objects or for scanning over the environment. The eyes work synchronically together so they are normally oriented to the same object and converge for near ones. Within the eyeballs there are also muscles like the iris which forms the pupil through which light passes through the lens and that lies immediately behind it, and by contracting or relaxing, controls the amount of light input. The iris is normally opaque for achieving its purpose, it's a pigment that helps the screening of light. The pupil is the hole formed by the iris through which light passes to the lens and into the retina. The pupil contracts to limit the rays of light to the central part of the lens and it does it also for near vision because that part of the lens is the best from the optical point of view. It also achieves the maximum aperture obtaining higher sensitivity in the absence of sufficient reflected light. Schematic of the human eye can be seen in Figure 1.

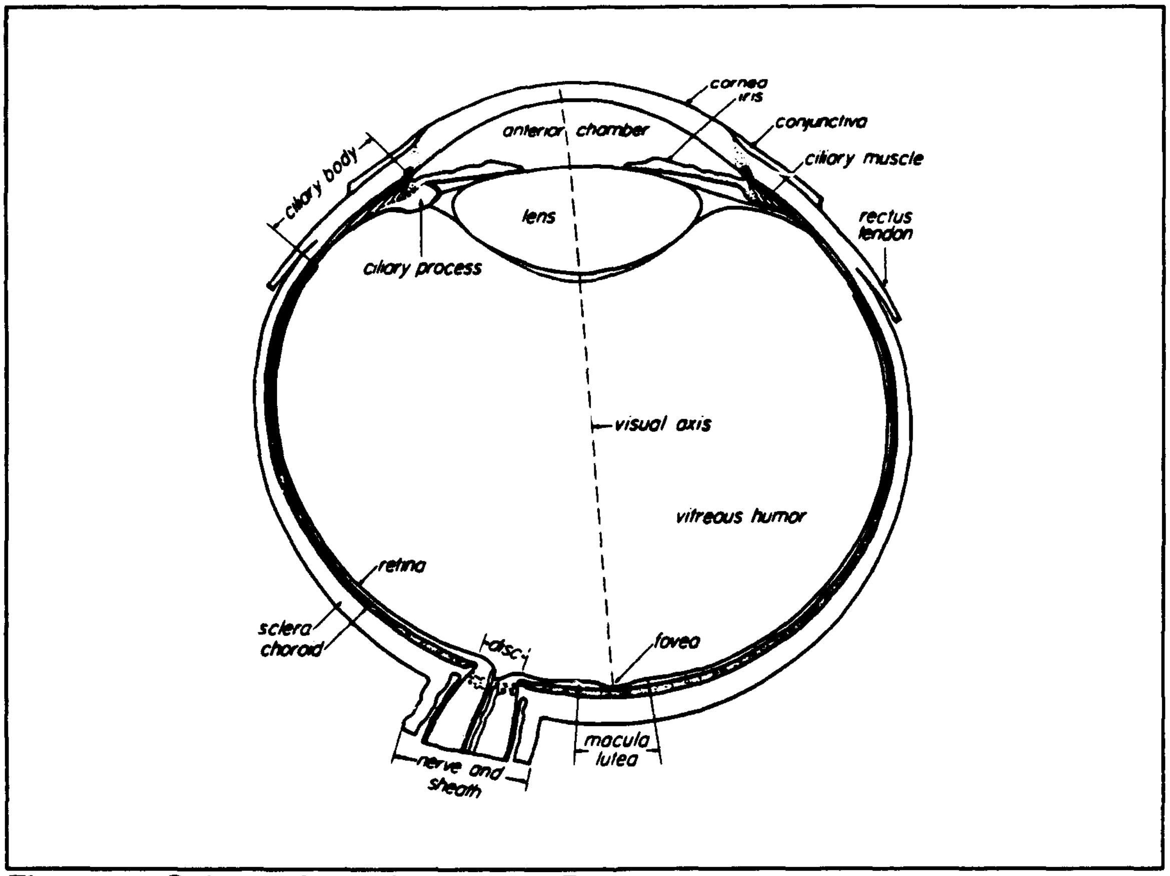



**Figure 1. Schematic of the Human Eye.**

The crystalline lens is important for the automatic adjustment by which the eye adapts itself to distinct vision at different distances by changing its shape. The radius of curvature of the lens is reduced for near vision as tension is released by the membrane that suspends it, thus becoming more convex and vice versa. The lens is built up of thin layers and built up from its center by addition of cells through its active life; the center is then the oldest part of the lens and in the measure that new cells grow around it, it is more separated from the blood system which supplies its oxygen and nutrients, so these inner cells die with time. When this happens, they harden, so the lens losses its ability to change its shape for accommodation to different distances. The retina is a thin sheet of interconnected nerve cells resembling a net, from which it derives its name, that covers the interior surface of the eye and over which images are displayed. The retina has a photoreceptive function with the use of the light sensitive cells namely the cones and rods. In the human retina exists approximately 7 millions cones and 120 million rods. But in the optic nerve there are only about 1 million fibers so this means that the information in the photoreceptors is compressed in such a way that it can be sent to the brain in fewer number of fibers. The cones and rods connect to the so called bipolar cells and this latter to the ganglion cells which in turn make up the optic nerve. This arrangement can be seen in Figure 2.

The retina contains two distinctive regions, the optic disk and the fovea. The optic disc is the exit point of all the nerve fibers that comprise the optic nerve and because of this structure it is a blind spot having no concentration of photoreceptors. It is fairly easy to find an observer's own blind spot by looking at one of two drawn small objects, respectively on the right and left margins of a sheet of paper, and by closing one of the eyes and moving the paper slowly toward and away at an approximate distance of 12 inches. This will enable the observer to get into a position in which the object that has not been fixated disappears, this means that its image is within the blind spot. The fovea is a

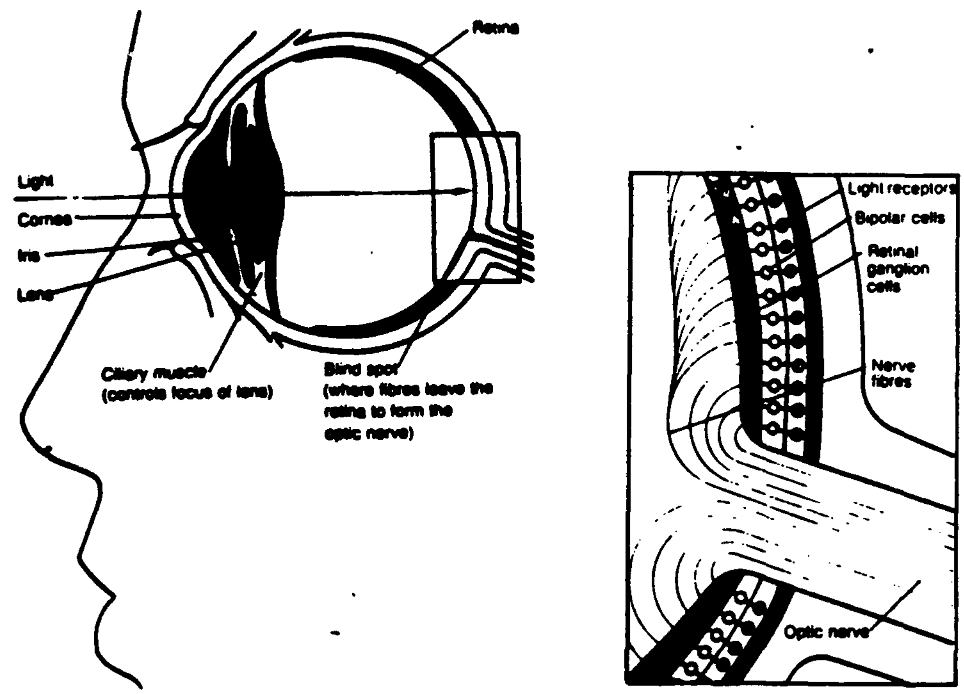



**Figure 2. Microscopic View of the Human Retina**

depressed circular region located in the macula or yellow spot of the retina which contains only cones in a high concentration converting it in the region of maximum visual sharpness for details and color. The cones are photoreceptors that are sensitive to spectral light allowing the perception of colors as well as grays. They require higher levels of stimulation intensity compared to the rods so they are more suited for daylight. The rods which are most concentrated in the periphery of the retina are very sensitive to light so they are the ones that permits night vision, but they do not distinguish color and their ability to distinguish one point in space from another nearby is very poor.

The shifting of the eyes optical characteristics for the purpose of focusing on any point is called accommodation. The accommodation of the lens allows therefore the automatic focusing, an optical feature of the eye that permits to focus on objects located at different distances. If we switch over gaze from a distant object to a close one, the refocusing will be performed in less that a third of a second and almost as fast for the inverse operation.

When a person wants to look at an object in detail or follow it when moving, he will have to rely on orienting the gaze line in such a way that it will impinge over the foveal region.

> Eye movements are necessary for a physiological reason: detailed visual information can be obtained only through the fovea, the small central area of the retina that has the highest concentration of photoreceptors. Therefore the eyes must move in order to provide information about objects that are to be inspected in any detail. (Except when the object is quite small in terms of the angle it subtends in the visual field.) (Noton & Stark, 1971, p. 3)

The time required for the cones and rods to adapt to an specific level of energy varies between them. Rods are about 1000 times more sensitive to light than cones but if we look at a bright light for a fair amount of time and then suddenly be subdued to almost total darkness, the time required for the eyes to adapt to the new situation will be fairly long until they approach an optimum value of sensitivity. Experiments have been developed in which the pupil has artificially been immobilized so as not to influence the results and have shown that for optimal retinal adjustments it takes up to 30 minutes. Distribution of the photoreceptors, fovea and blind spot can be noted in Figure 3.

In another type of experiment in which light was directed along the central axis of the pupil and also through the edges of it, an interesting fact occurred. Only the cones are affected by directional sensitivity, this is, the light that strikes directly over the photoreceptor axis is more effective that if it strikes in an oblique fashion. For the rods it was found that they are equally responsive to direct or indirect light. Visual acuity is however highest in the central axis of the visual field which is in the center of the fovea, with which the eyes do the fine detail and optical vision and where the density of cones is higher. It is important to mention that, including the fovea, as the peripheral angle increases, the visual acuity decreases, and the number of photo receptors which converge to each single bipolar cell and the number of these latter which converge to the single ganglion cell, also increases rapidly. This structural composition and qualities of the peripheral retina and the fovea leads to the definitions of peripheral vision and foveal vision.

Peripheral vision can be best explained by using a simple experiment. If a person maintains a gaze oriented perpendicularly to the front and the arm subtended in the same horizontal plane and to the right, with the thumb pointing up, by sweeping the arm slowly to the axis of the gaze an observer can notice how, a blurred image becomes a well defined one. The portion of the visual arc in which the object, in this case the thumb, is being seen blurred corresponds to the peripheral vision, this is, the visual response of the eye without the

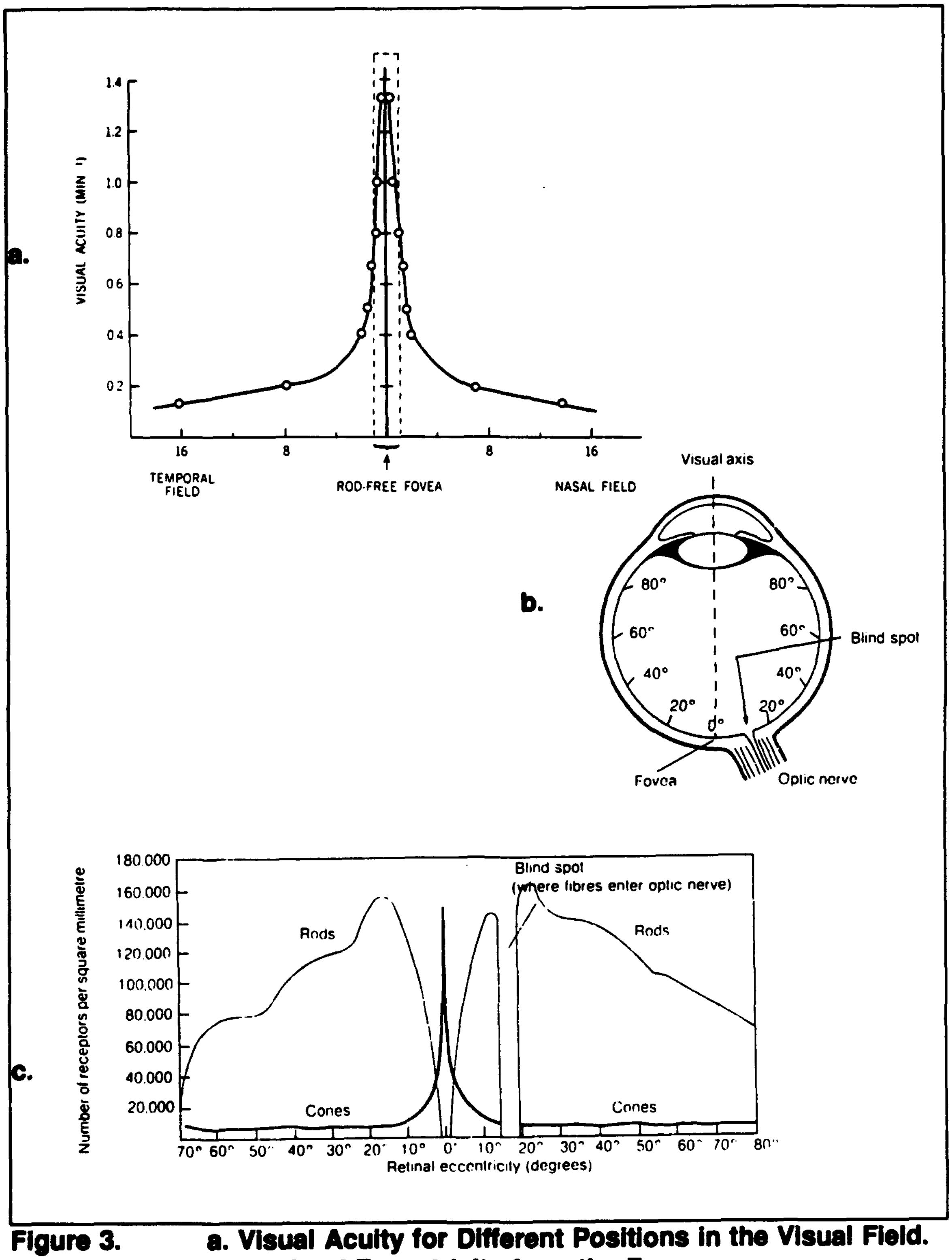



**Figure 3. a. Visual Acuity for Different Positions in the Visual Field.**
**b. Angle of Eccentricity from the Fovea**
**c. Distribution of Rod and Cones**

collaboration of the fovea. Peripheral vision is therefore unable to visualize in a fine detailed fashion, for this activity is relied solely on the fovea. Humans are therefore required to orient their eyes to specific angles in order to obtain detailed information about their environment to this type of vision is what we define as foveal vision, which corresponds approximately to half of a degree at the retina and not more than several degrees in the subjects field of view. To overcome this limitation humans move the eyes at incredible speeds, movements from fixation points to another which are called saccades and will be analyzed in the next chapter.

## D. HAPTIC SYSTEM

The haptic system is one of high complexity and refinement and is very sensitive to stimuli such as temperature, pain, texture of surfaces and others. Here we will stress on those abilities of the system to detect kinesthesis information, this is, spatial and temporal information arising from the vestibular apparatus, muscles, tendons and joints.

An individual must be able to detect and control its own movements and also know the relative spatial positions of the different parts of its body. In order to perceive its orientation relative to the ground and the effects of gravity toward its body, he requires enough information that permits balance and equilibrium. He accomplishes all of this with the full employment of the haptic system, understood as the individuals capacity to sense the adjacent boundaries of his flesh by the use of his own body: skeleton, muscles, joints, skin, etc. acting as an interdependent system.

> The haptic system, then, is an apparatus by which the individual gets information about both the environment and his body. He feels an object relative to the body and the body relative to an object. It is the perceptual system by which animals and men are literally in touch with the environment. (Gibson, 1966, p. 97)

### 1. Vestibular System

This is one of the systems responsible for our ability to maintain a vertical posture and orient ourselves relative to the ground. It is composed of a structure called the vestibular apparatus, as shown in Figure 4, located in the same cavity as the inner ear which in a very general definition can be described as three interconnected semicircular channels which are oriented in right angles relative to one another resembling the three dimensional axis x,y,z. This particular disposition obviously permits maximum sensitivity to body or head motion in any plane. Each channel broadens at one of the ends forming a space in which mechanoreceptors are accommodated and which suffer a mechanical deformation every time they are subjected to changes in angular acceleration.

Depending on the direction and magnitude of the mechanical deformation, the receptors generates a positive or negative electrical potential and since they are attached to synaptic or nervous junctions these carry the signals through the vestibular nerve. This apparatus is one which responds when stimulation is applied with no conscious process involved in an automatic fashion, permitting the person to maintain its equilibrium when static or in motion. People

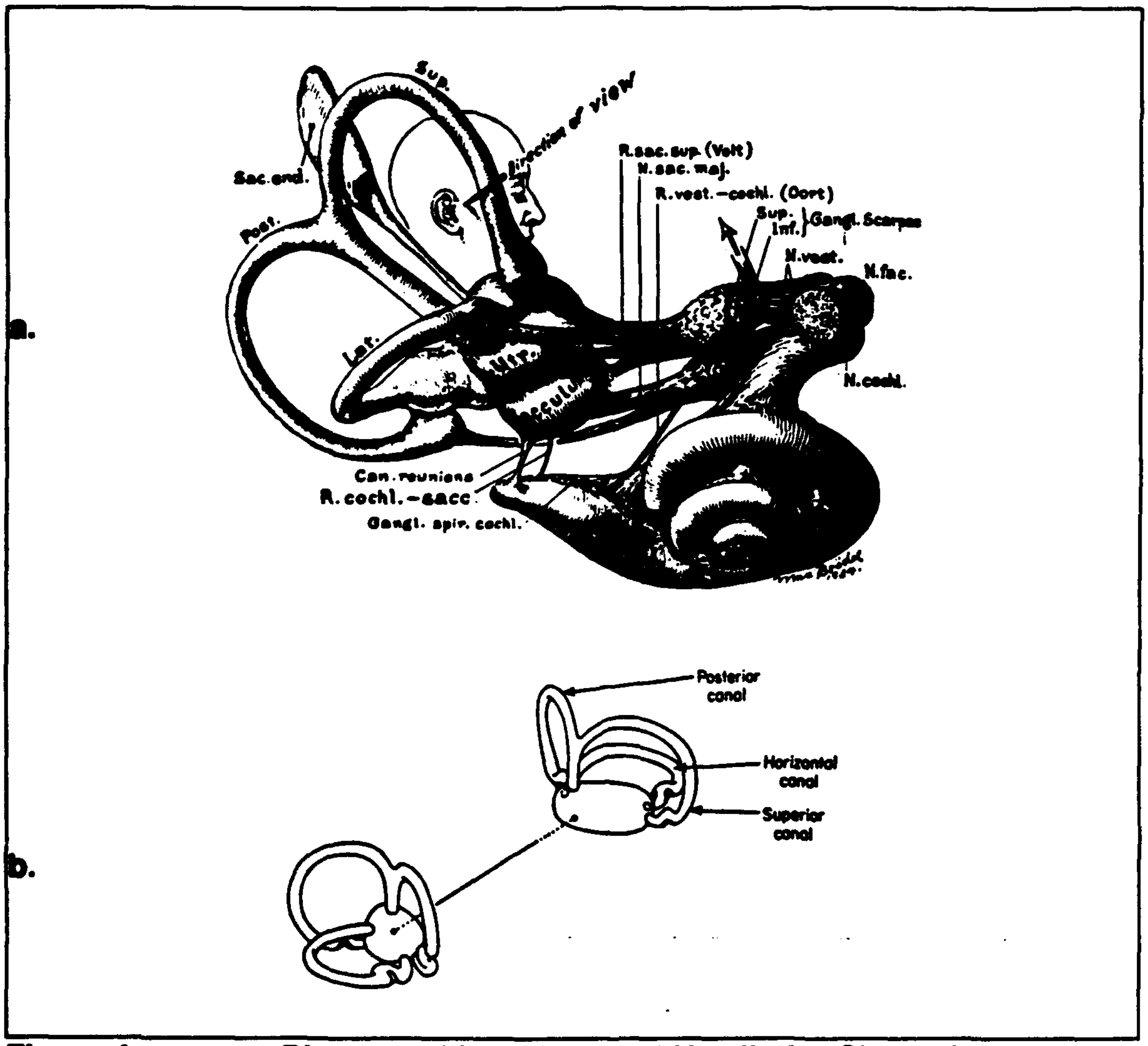



**Figure 4.** **a. Diagram of Inner Ear and Vestibular Channels**
**b. Arrangement of Vestibular Apparatus on Each Side of the Head**

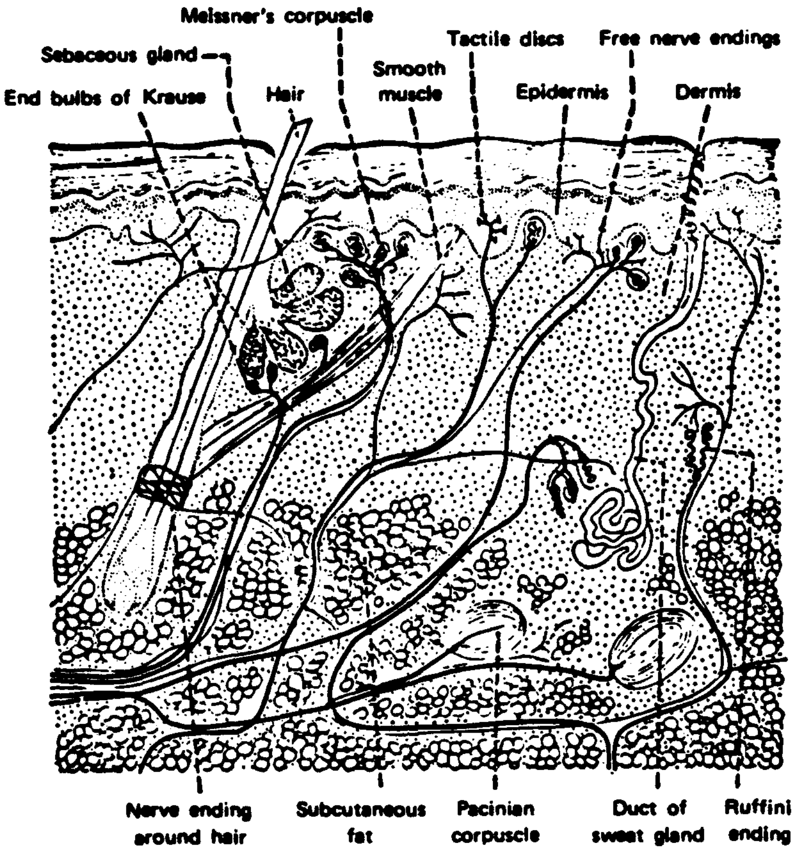
that work in unusual environments where the vestibular organ is subjected to increased activity, like seamen, well know the initial effects of dizziness and nausea, but after a certain period of adaptation the symptoms fade away.

## 2. Mechanoreceptors

These receptors are spread all over the skin and under it, in the joints of bones and their ligaments, they are present in muscles and tendons, below hair follicles and under nail attachments, they are virtually almost in every part of the human body, but of particular interest is that all of these parts are ones which have the ability to move and with this, they offer tactile and kinesthesis information.

The Pascinian corpuscle which responds only when submitted to touch stimulation, has been the most widely studied mechanoreceptor and is a good example of how the skin is able to sense touch. Meissner's corpuscles and Ruffin's endings are other type which are able to sense touch but they can also sense warmth or cold. The Pascinian receptor is composed of dendritic endings encapsulated in a multi layer structure with alternated fluid and tissue layers. A composite diagram of the skin and its components are shown in Figure 5.

An electrode connected to its interior has been able to record the responses of it finding that it is extremely sensible when pressure is applied producing an electrical potential, and if no further variation in pressure is carried out, the potential decreases gradually. When the pressure is removed, the phenomenon repeats by creating an electrical potential and decreasing again. Something important to note here is that if stimulus remains constant, the receptor gradually adapts to it which makes our skin not very good to detect steady-state conditions but rather the changes produced within specific periods. These receptors are found in muscles, tendons, joints and skin of the body and are able a.




b.

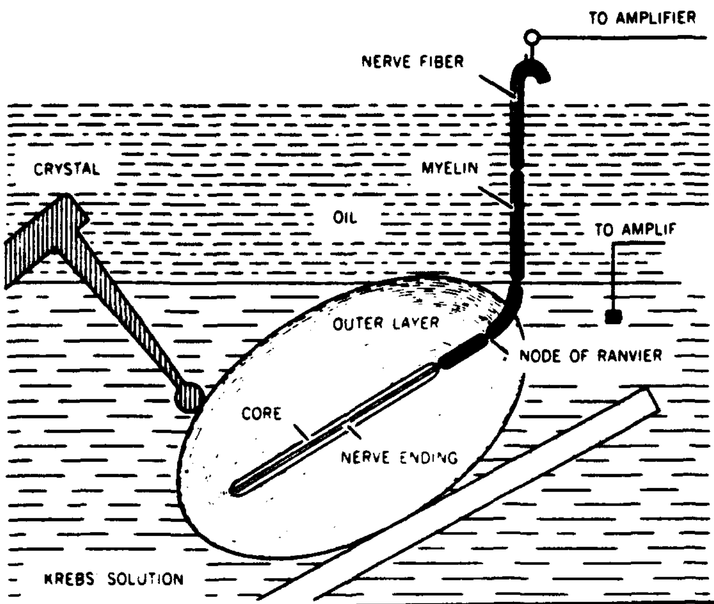



**Figure 5.** **a. Schematic of the Human Skin.**
**b. Pascinian Corpuscle Mechanicaly Stimulated with Recorded Response.**

to reflect both the magnitude of displacement and the velocity in which the receptor is being deformed. They are concentrated in a higher degree in some parts of the body like in the tip of the fingers and the palm of the hand while on the sole of the feet are more dispersed.

### 3. Tactile Sensing

The skin in humans contain subordinate indirect receptive units such as hair follicles and nails. This is, when object proximity is sensed by skin deformation it can occur through one of these units. Since mechanoreceptors lie beneath the nail and hair follicle's base, the stimulus is detected. Texture of a surface can be explored by scratching it or presence of an object by grazing it with the hairs.

> The capacity of vibrissae, hairs, claws and horns to feel things at a distance is not different in principle from the ability of a man to use a cane or probe to detect the mechanical encounters at the end of the artificial appendage to his hand. (Gibson, 1966, p. 100)

But as we will see when describing kinesthesis, many other variables are involved when a man relies on a probe to detect mechanical encounters if he is also using his body and extremities for doing so. In this section we will refer to tactile sensing as when human uses his skin and fingers from hands and feet, to gather information about his surroundings.

The manipulation of objects for example, offer the possibility of detecting volume, texture, weight, an approximation of the center of gravity, rigidity, elasticity, shape, temperature, relative spaces between features of the object, etc.

When grasping an object or touching it with the finger tips, we have the possibility of collecting information from at least ten different points which have relative orientations and spacing. If we also use the palms and by different modalities of touching like running, sliding, squeezing or exerting pressure over the surfaces, the amount of information we can obtain is considerable. We can also use each hand independently for the purpose of comparison between relative conditions, for example detecting which surface area of an electrical motor is hot or cool.

> The surgeon's techniques of percussion, palpation and massage can often give him more information about the special states of the interior of the human body than any other medical test. (Katz, 1936, quoted in Gibson, 1966, p. 129)

We have all encountered the situation of blindness because of imposed conditions and in those moments we are well aware of the information gathering capacity of the sense of touch which we could say that greatly approximates to that of vision if we are allowed to proximal objects.

> We are not accustomed to think of the hand as a sense organ since most of our day to day manipulation is performatory, not exploratory. That is, we grasp, push, pull, lift, carry, insert or assemble for practical purposes and the manipulation is usually guided by visual as well as by haptic feedback. (Gibson, 1966, p. 123)

**4. Proprioceptive or Kinesthesis Sensing**

Historically, the "muscle sense" had been taken as the sixth sense. Kinesthesis is defined by the psychology Almanac as:

> The muscle sense. Sensations within the muscles, joints and tendons that provide perception of bodily movement, position or weight. For example, the

feeling of bending the arm or moving the fingers, perceived independently of the sense of touch....In 1906 Sherrington proposed proprioception as a more inclusive word. (Wilkening, 1965, p. 94)

Knowledge of bodily movement or position can be accomplished with the information available from the different nerve endings or base endings that are spread all over the muscles and joints and which have branch or spray shapes that are stimulated when squeezed. These arrangement can be seen in Figure 6.

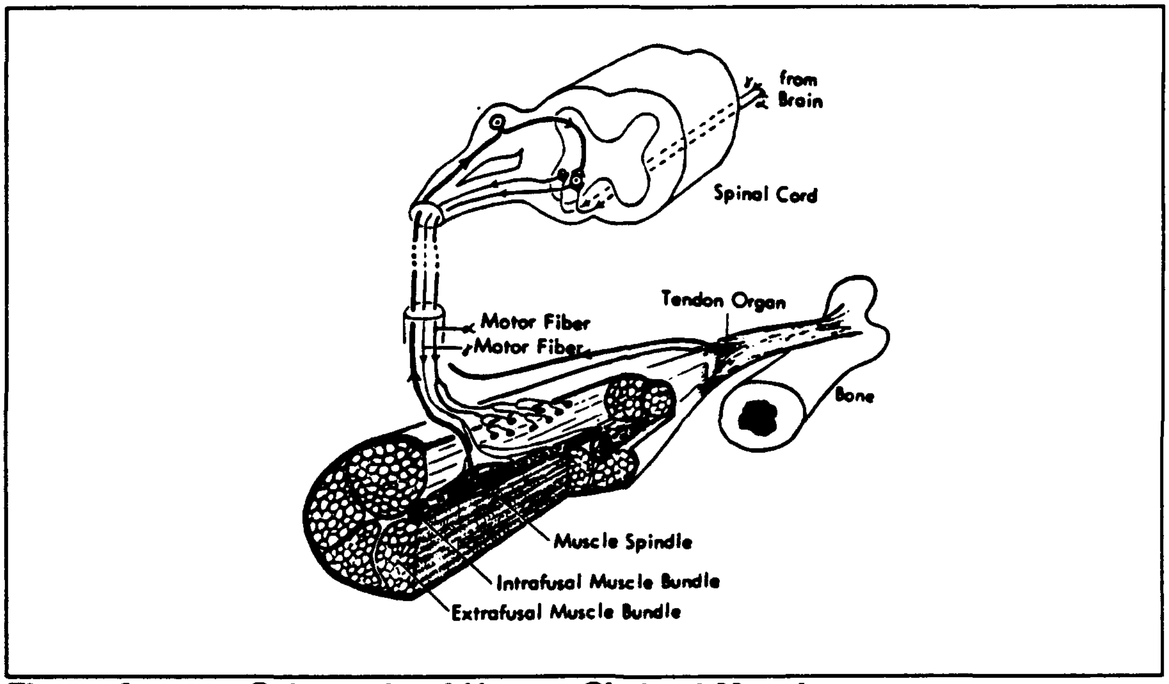



**Figure 6. Schematic of Human Skeletal Muscle.**

There are also Golgi-type endings which are also known as muscles or tendon spindles which are a type of capsulated nerve members, that perceives tension in these members. Muscle spindles are displayed along the muscle fibers thus being oriented in parallel with them and are able to measure any change of the muscle length, while the tendons are connected in series with the muscles and since these are the means in which muscles are attached to the bones. Therefore the receptors in tendons are able to perceive changes in muscle tension.

J.J. Gibson suggests a classification of the muscle systems in various categories according to their function, exploratory or performatory. Of interest for this research are the following:

> 1. The postural system. The body need not "move" at all, except for small compensatory movements to preserve equilibrium. There is orientation to the earth. This system is fundamental to all others.
>
> 2. The orientation - investigating system. Movements occur, turning movements, but also mere postures of pointing and fixating. These are adjustments of the head, eyes, mouth, hands, and other organs for obtaining external stimulus information. There is orientation to special features of the earth, not just to gravity.
>
> 3. The locomotor system. Movements occur that put the animal in a more favorable place in the environment, such as approaching, pursuing, avoiding, escaping.
>
> 4. The performatory system. Movements occur that alter the environment in ways beneficial to the organism, such as displacing things, storing food, constructing shelter, fighting and using tools. (Gibson, 1966, p. 57)

The flower-like nerve endings also are located in the bone joints and are able to present information concerned with their variations in angle aperture. Experiments carried out by application of anesthesia to muscles and tendons have shown that humans are still able to perceive variations in joint angles: it was found that the shoulder has a high degree of sensitivity being able to discern displacements of 0.22 - 0.42 degrees at a speed of 0.3 degrees per second. These nerve endings have the capacity of measuring angle changes in a range of about 15°, but they perform in a tandem fashion in such a way that when one has traversed the 15° sensing range other have initiated its response, embracing this way all possible ranges. They do so by increasing the firing rate amplitude of response when reducing the joint angle and decreasing it when augmenting the angle. They are also able to measure the speed in which the variation of angle is performed, and they achieve it by varying the rate of change of their response and the time required for obtaining the steady state, therefore exhibiting a steeper slope for fast changes and vice versa.

As we have seen, the body counts with different types of receptors that are stimulated by movements and actions of the individual's body. Such receptors that sense proprioceptive activity are referred to as proprioceptors, this includes also the vestibular apparatus. The human skeleton is made up of around 100 mobile joints which in conjunction with the bones and muscles from a type of structure that permits mechanical stiffness and compliance according to its needs.

> The bones are linked by hinges to the spine and the head. The trunk branches into four limbs and each limb branches into five digits.....In order to understand touching, as well as locomotion and manipulation, we must keep in mind this relation of the body to its extremities. For the movement of any bone can only be a movement relative to the next bone inward....The fingers can move only as the knuckles bend, the hand can move only at the wrist relative to the forearm, the forearm only at the elbow relative to the upper arm, and the upper arm at the shoulder relative to the trunk. The merest twitch of a fingertip therefore, is linked to the spine by a series of six joints.... The disposition of all the bones, at any moment in time, can be thought of as a sort of branching vector space in the larger space of the environment, specified by the set of the angles at all joints relative to the main axes of the body. (Gibson, 1966, p. 102)

A view of the skeleton bones, joints and muscles are shown in Figure 7.

a.

b.

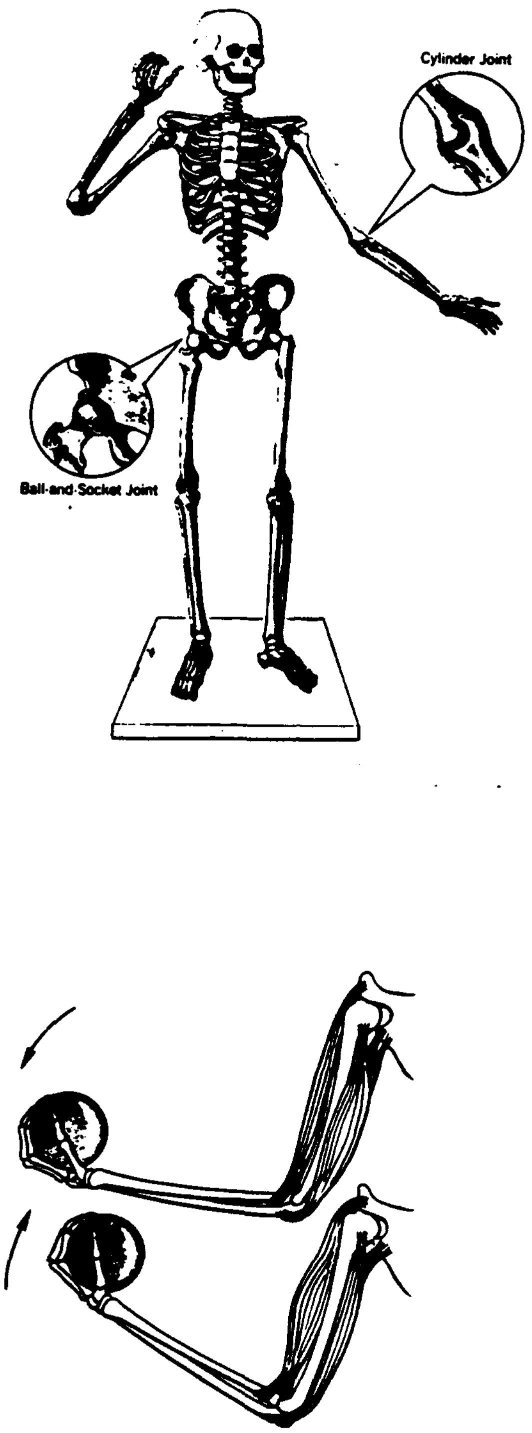



**Figure 7.** **a. Human Skeleton.**
**b. Bones, Joints and Muscles.**

But we have to be aware that these are not exclusive organs or receptors which register bodily movement sensitivity. We have to recognize that vision can detect movement by monitoring relative displacements of members of the body or by variations in the ambient light, the auditory system is able to detect echo feedback or sounds of movements, the inner ear can also detect locomotion. As we stated before all of this systems operate concurrently and simultaneously.

The haptic system is therefore capable of measuring distances and spaces by which the individual has the opportunity to evaluate the incoming perceptions. If you try to match the fingertips of both hands at any given speed or angle of aperture without looking at them in their action, you would be surprise by the accuracy of success. Ballet dancers are executors of the haptic capabilities with harmonic precision.

## E. APPLICATIONS BACKGROUND

### 1. ROVs

Remotely operated vehicles have been under development trends for the past few decades. Basically they are vehicles which permit extended space control by main stations through means of electrical, electronic and mechanical hardware in order to perform specific tasks at a distance from their support platforms. There exists different types of designs applicable for a vast number of purposes but they are mainly used for observation, handling of materials, or manipulation of instruments and tools. Most of the ROVs are linked to a surface platform from where they are controlled and supplied with electrical power unless they are fed by batteries, and to which they are sending data in visual form through T.V., cameras .or by different types of transducers which show their environmental contacts. Usually they have one or several mechanical manipulators for recovering objects or specimens from the sea floor or for handling tools to perform underwater tasks, specially in supporting divers activity. They can be of the self propelled type or towed by a ship, designed for midwater operation or in contact with the bottom of the sea, some have the capability of maneuvering in 3-dimensions. Undoubtly ROVs have been of great help in some fields of application specially as in off-shore oil platforms, pipe and cable installation and inspection, accident investigations, observation for development of rescue and salvage plans and particularly for diver's monitoring and assistance. They can operate in hazardous environments or in unaccessible conditions by a human such as freezing temperatures or excessive depths, but on the other hand ROVs still suffer of major limitations specially when performing in submarine environments. The man-machine interface is the greatest of these limitations since they operate with manipulator controls which are not anthropomorphic and do not resemble with fidelity the surrounding conditions of the vehicle. Most of the today control stations are complex to operate and often require several crew members to do it. ROVs also suffer, from limited ability for swift, smooth and precise motions as well as constrained visual acuity due to presence of organic water components and debris, lack of light, limited visual field and accommodation to environmental conditions, distortion of size and distance of objects due to the medium and poor dexterity of mechanical manipulators and sensory feed back. When the ROV is tethered, which is in most cases, as shown in Figure 8, entangling of the cable with the controlling surface platform or around the objects being explored, can cause loss of time, malfunction of the vehicle or even getting it lost.

Because of all these disadvantages, ROVs generally perform precise preconceived operations. Their cost is high because of the necessity of very well trained operators which do not guarantee success in every maneuver attempt, and sophisticated hardware such as optical vision systems and controls.

### 2. Next Generation of ROVs

In order to overcome the limitations and disadvantages of current ROVs, technology is being developed in order to achieve a more coherent and capable systems for vehicles which should enhance the improvement of the interface and integration between humans and machines. This could be accomplished by the implementation of telepresence or virtual reality which in essence will provide the remote operated vehicle with at least the same capabilities of a diver and in some cases even improved ones, such as incremented ranges of detection by the use of sonar scanners which can detect underground or distant objects. The concept of telepresence is that in which the human capabilities of sensing and modification of its actuation according to the environmental conditions and to the task to be accomplished, is extended at remote distance from the station of control. The new generation of ROVs can be then defined as TOPs which stand for teleoperator-

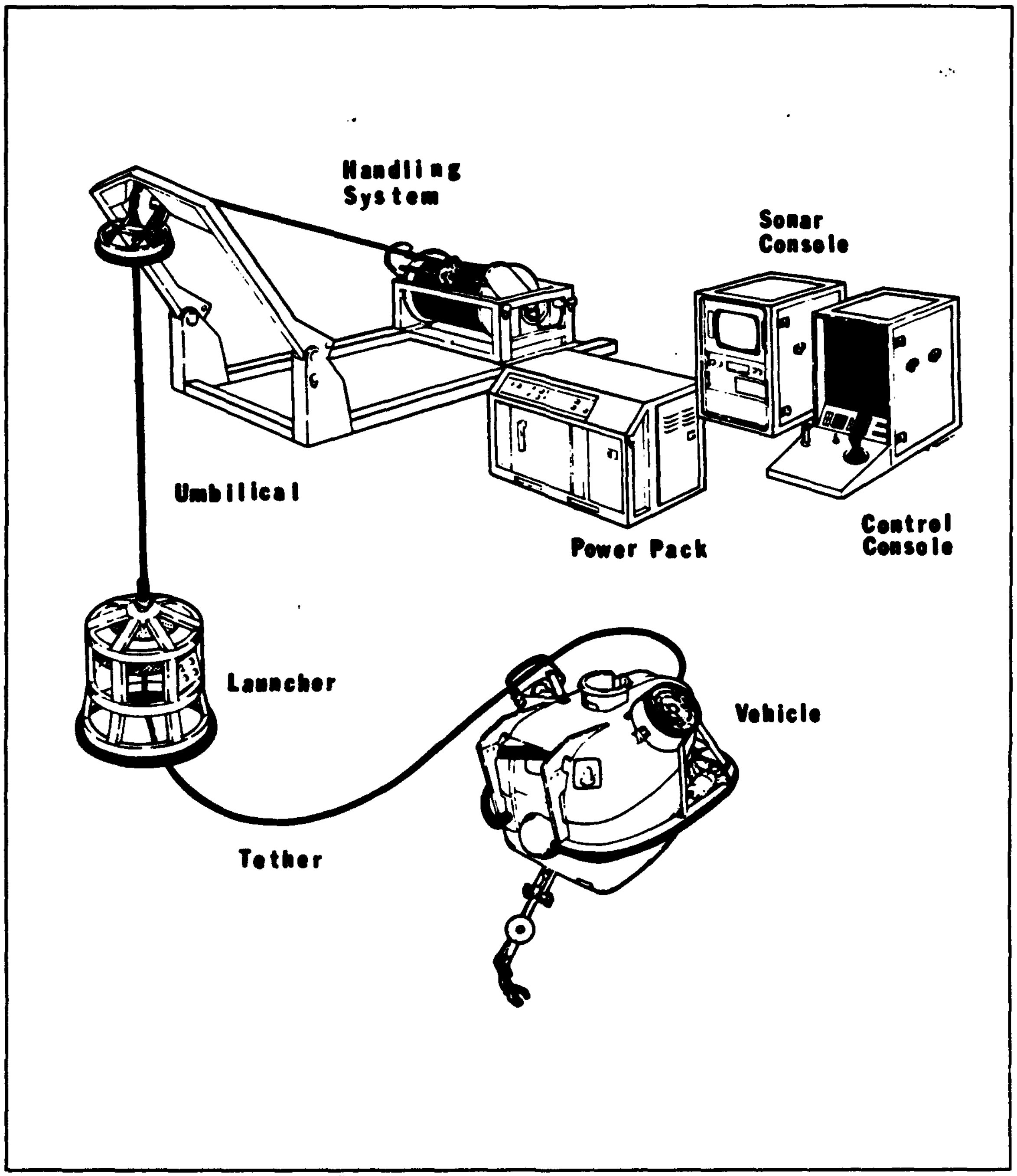



**Figure 8. General Configuration of a ROV System.**

telepresence systems, and what it aims at, is for technology development that will allow an operator in a remote work station to perform as if he were the actual diver who was executing the task in situ with capability of judging readapting and being consequent with any change in the actual conditions of the advancement of the work. Telepresence is thus the transmission over a distance with the capacity and advantages of the immediate proximity. This is, counting with an environment which is a replica of a remote one, affording the capacity of transmitting movements or commands which are going to be exactly reproduced. This offers the great advantage that the operator can be located in a safe remote location separated from a potential hazardous environment.

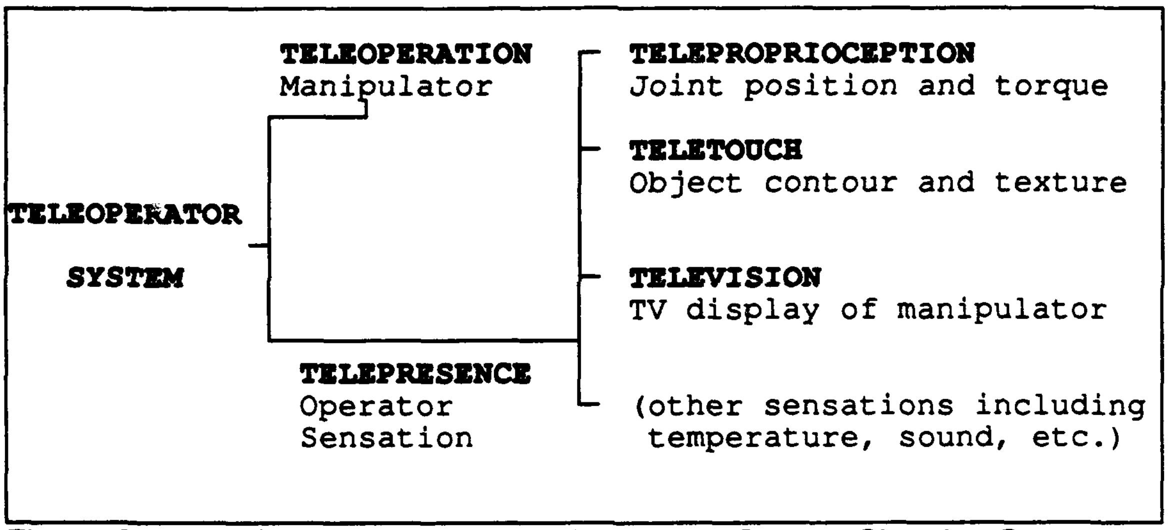



**Figure 9. Configuration of a Teleoperator System Showing Separation of Proprioceptive and Tactile Sensory Feedback.**

The application of telepresence is useful in almost any field of human life. In outer space, astronauts are constrained by excessively thick gloves which are essential for their protection against micrometeoroids and for thermal insulation purposes during activities outside of the space vehicle. This invalidates the haptic system to perceive objects and manipulate tools adequately. For military purposes, telepresence is of invaluable advantage for handling explosives, deactivating mines, night vision or conduction of surveillance, reconnaissance and utilization of remote operated vehicles. Handling of nuclear elements as well as high voltage transmission equipment offers safety for the operators. In the mining industry, detection and identification of metals and minerals could be done at reduced costs. In the medical field the detection, identification and manipulation of internal organs of the patient with the utilization of telemanipulators could avoid in some case physical costs and endangering of the individual. For the comforting of disable and handicapped persons, telepresence is of the upmost importance.

Some other means of augmenting this improvement of human-machine interface is by the application of virtual reality which in its basics is the creating of three dimensional images that can be "grasped" by the observer which is viewing them through stereoscopic goggles and position sensors while computers displaying through miniature television screens a 3-dimensional model of the environment, receive information of the position and orientation of the observers head. The utilization of tactile/force feedback sensors and audio interaction help to recreate this virtual world. As conceptually represented in Figure 10.

It is known that divers rely on the haptic system for most of the perception of their proximity as when developing an activity of rescue or exploration, because their conditions for visual apprehension are diminished due to the reduction of light available and sometimes presence of buoyant mud. We

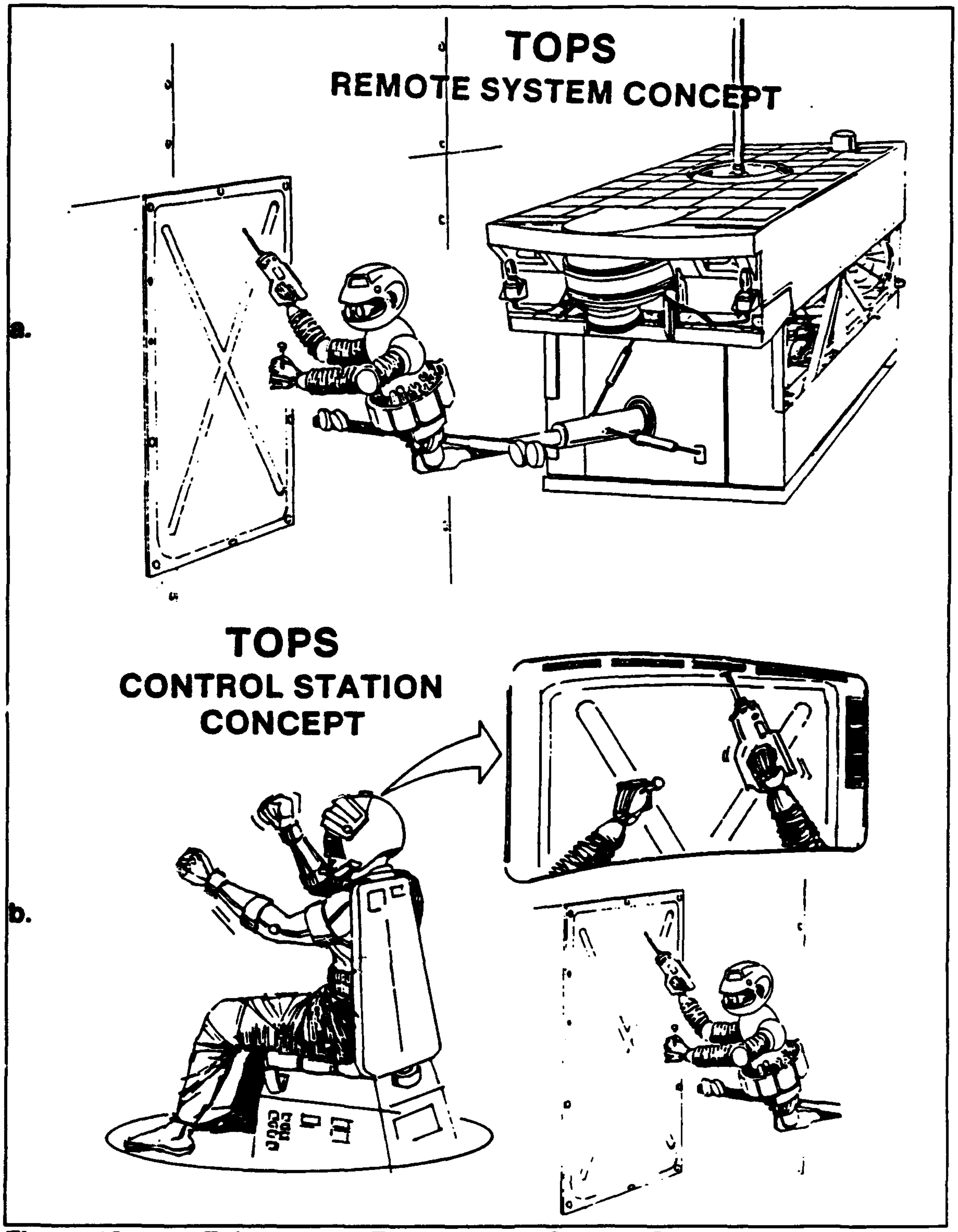



**Figure 10. Teleoperator/Telepresence System Concept.**
**a. System**
**b. Control Station Concept**

can recreate a typical scenario for a divers task by imagining how can he recover an specific object of for example an electronic component that is encapsulated in a metallic box in the cockpit of a sunken airplane. He must first detect the presence of the airplane and its orientation relative to the ocean floor in order to proceed to this interior. He must do so by touching surfaces and maybe tapping on them if visual conditions do not allow an immediate recognition. The diver must orient himself using all the possible stimuli available for perception thus he must use his stretching and contracting arms and legs in order to sense mechanical contacts and obtain a spatial order of these contacts. By sequentially detecting edges and corners, straight or curved forms he may reconstruct a model in his brain based on the gathered information, taking care not to loose contact with the object. By touching and scanning objects he may be able to recognize the one that calls for his interest and proceed for its recovering by manipulating the required tools that will enable him to acquire the object. For this latter activity the diver relies again on the haptic system in order to orient the tool and match it correctly with screws or any other similar type of elements of the device. Having opened the casing he must then select which component is the correct one and he must do so by recognizing by touch all the fine features that identify without doubt the given one. His return to topside must be done in the same manner.

The implementation of more natural haptic systems for gathering information would ultimately allow to enhance the work environment exploration and recognition, approaching thus to limits of telepresence and virtual reality and in some cases habilitating the haptic system to substitute expensive and complex vision apparatus since both systems share components which categorizes them as equivalent.

## F. OBJECTIVE

This research is focused on the primary objective of being able to explore how humans formulate haptic information gathered through the proprioceptive component of the haptic system. It focusses on the method by which features of a set of objects are explored and how they are integrated and combined in order to construct a higher level model that eventually will provide the subject with sufficient information as to recognize the object being explored.

# II. THEORY

## A. SCANPATH THEORY

Due to the visual acuity constraints imposed by the fovea, the eyes must move fixating the gaze over those features that call an observer's attention when exploring any stationary object. If it were to be examined in detail, several fixations over particular primitives must occur. Saccades is the name with which sudden fast alternating movements of the eyes that separate successive visual fixations are defined. They can occur at very high velocities as large as 1000 degrees per second in their peak and they occupy only about 10% of the viewing time spending the 90% of the rest fixated over particular points. These movements occur in an apparent random jerky fashion, but experiments and data gathered of actual eye movements have shown that by no means these movements occur in such random order. Alfred L. Yarbus, *et al.*, have been able to reconstruct the order in which a subject produces fixations points over a photograph while recognizing it, as mentioned by Noton and Stark, as represented in Figure 11. They show, by lines representing the saccades, that humans normally follow a particular order and do not interact with the picture in a total random way but rather a pattern is created that is proper for a given subject, while viewing a given picture. This pattern is created by the observer when he sees the picture for the first time, a period that can be defined as the learning or construction phase. Apparently during

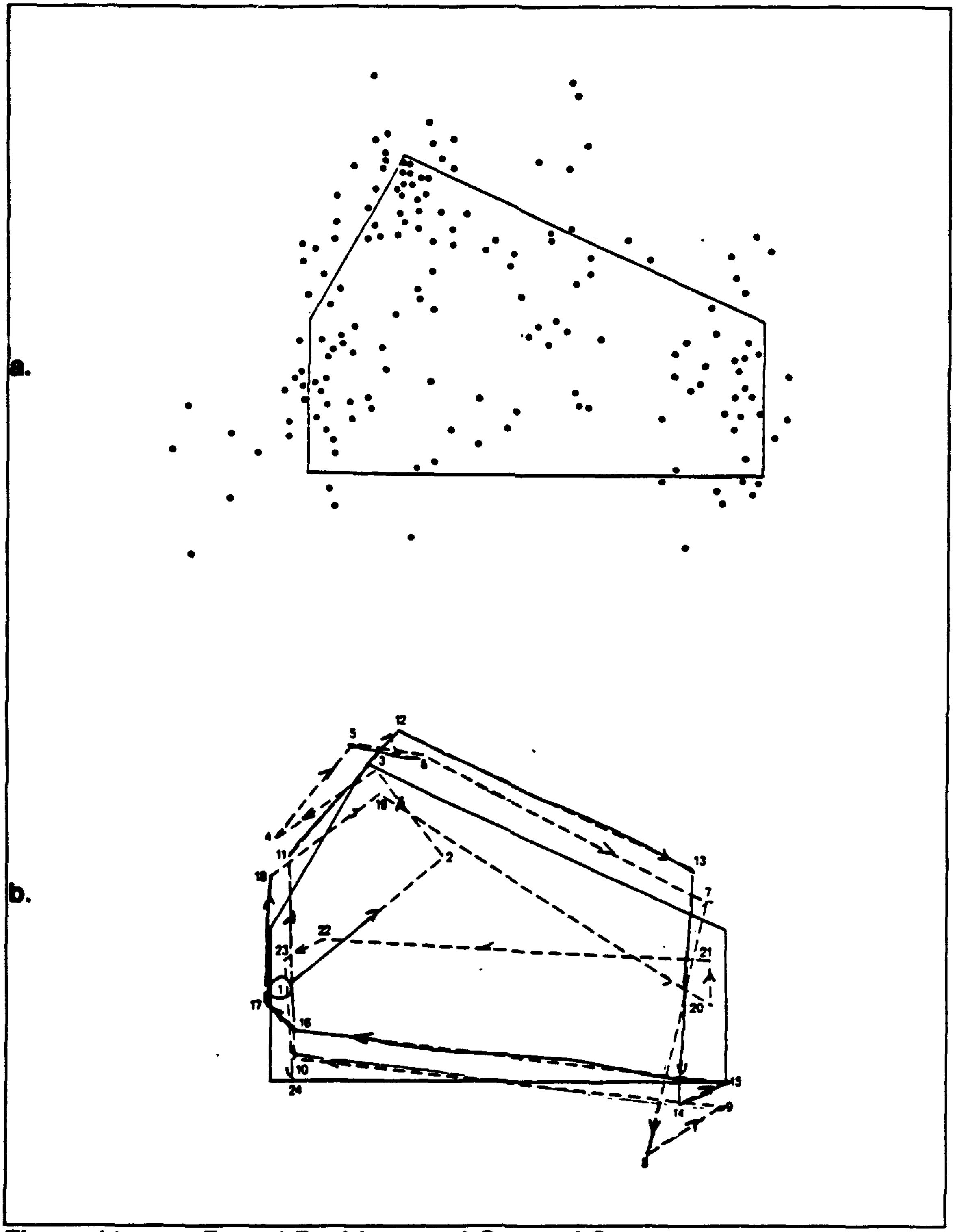



**Figure 11. Foveal Positions and Order of Saccades.**
**a. Polygon and dots that indicate fixations of fovea.**
**b. Sequence of fixation or saccades.**

this time the observer is retaining as an internal representation in his memory features of the picture in the sequence that they were observed. These sequences are defined by David Noton and Lawrence Stark as scanpaths and they refer to the pathways that are displayed by the sequence of saccades.

> Each scanpath was characteristic of a given subject viewing a given picture. A subject had a different scanpath for every picture he viewed, and for a given picture each subject had a different scanpath. (Noton & Stark, 1971, p. 5)

By presenting drawings fairly large and close to the subjects eyes this would subtend about twenty degrees of visual field and thus the observer would be forced to produce the scanpaths in order to recognize the pictures. A typical scanpath of Noton and Stark experiments consisted of about 10 fixations and duration of about three to five seconds. Scanpaths usually occupied from 25 to 35 percent of the subjects view time and the rest being used for less regular eye movements. Scanpaths were not always observed but the more common reaction was to exhibit one. They predict that when a subject views an object for the first time he scans it until getting familiar with it, developing a scanpath that would be stabilized as memory traces which fixate the sensory and motor activity simultaneously. When the subject is faced with the same object again, he eventually will recognize it if he is able to match his memory representation by verifying the successive features and repeating the memory stored scanpath. The result of the experiments showed that in fact scanpaths were built during the learning phase and repeated themselves during the initial recognition phase, this latter is understood as the period in which a subject views an already familiar object for which a scanpath had previously been constructed. Thus the first eye movements on viewing a picture usually followed the same scanpath that had already been developed during the learning or construction phase. This infers that the subject was actually matching the internal representation of the original scanpaths with subsequential ones in order to find a matching pattern that would facilitate the recognition of the object. Another result found was the fact that if a subject develops a particular scanpath for a given object this suggests that the scanpaths are not a result of a given recurrent eye movement habit but rather a natural response of the subject when submitted to a visual stimuli. Similarly, the fact that different subjects developed different scanpaths for the same given picture suggests that the scanpaths are not determined by specialized peripheral feature sensor that control eye movements otherwise similar results might be expected for different persons. Even though a clear pattern was found in the results of scanpath experiments, on the average only 65 percent of the times it was displayed during the recognition phase and leaves the other 35 percent still without explanation.

## B. SEQUENTIAL SEARCH HYPOTHESIS

The Gestalt theory shows propensity for a unified whole, pattern or organized field having specific properties that cannot be derived from the summation of its components parts. Opposed to it, the sequential or serial hypothesis proposes that the internal representation is an assemblage of step by step construction based on the objects serially identified features. During recognition, the memorized patterns are matched with the observed ones and a successful matching would complete the recognition. Experiments that have been developed to explore this hypothesis are supported mainly by the time that the subject takes to identify an object. Different small objects that can be identified by only one fixation and that are usually abstract figures, limiting the subject to see beforehand but only few of them, which have been classified as the target objects. When presented to the subject, the time he spends in recognizing the figures or either rejecting them as target ones, is recorded with sufficient accuracy. Noton and Stark show that this type of experiments normally yield two general results. A subject takes longer time to recognize a target object than to reject a non familiar one and if the serial hypothesis is correct this is the behavior to be expected since it will be required to inspect feature by feature while in a parallel or holistic manner the matching operation would have been done in only one step. In a serial pattern when a non-target object is inspected it will be rejected sooner since the matching operation will fail at an early step without further checking the rest of the features. Another type of result arises when using objects of more complexity in their structure. It has also been observed that the subject spends more time inspecting then which also supports the serial step by step feature recognition hypothesis since more features have to be inspected in order to obtain a match. Gestalt theory has proved that to a certain degree there is certainly some sense of unity that pertains to an object that unequivocally identifies an object even before any type of recognition patterns arises, but this seems to be more true as an object becomes more familiar and very well known by a subject who will only require to glimpse at it to fulfill recognition.

## C. RESTRICTED VISUAL SEARCH

Dr. Akira Watanabe developed experiments using instrumentation that could measure the fixation points of an observer looking at a television screen (Driels, 1991, p. 3). By this means the foveal visual component was able to be decoupled from the peripheral region by masking this latter and thus allowing the exploratory strategies used by the subject to be observed. It was noted that if visual conditions for a subject were constrained to the foveal component alone, the natural response for apprehension would immediately shift from parallel to a sequential search type. This behavior is not surprising since the foveal visual field angle is confined to small values that compels the observer to search in such a manner in order to maintain a visual contact with the object. In the event that the subject were exploring a fairly large object close enough that he could not loose contact with it and therefore used parallel search strategies with only foveal visual component, he would be able to inspect in fine detail the features he encountered but would not have a sense of their relative spatial arrangements. This would enable the feature integration required for constructing a model of the inspected object. On the other hand, if only peripheral visual component were present the object would be explored using a parallel search strategy because the image would be seen in a blurred outline form that would inhibit its recognition.

## D. HAPTIC SEARCH

Remote manipulation of objects using a feedback telemanipulator device has been accomplished with experimental work developed by Professor M. Driels and H. Spain (Driels & Spain, 1990, p. 71). The layout of the mechanical arm between the operator and the object is reflected by the decoupling of the proprioceptive and tactile components of the haptic system. Using wooden letters of the alphabet, as shown in Figure 12, and masking visual and auditory cues the operators were requested to identify the objects by means of the telemanipulator which was one of the force reflecting terminus type. The letters were presented lying on a metallic taskboard in a random orientation and were also selected in an aleatory sequence.

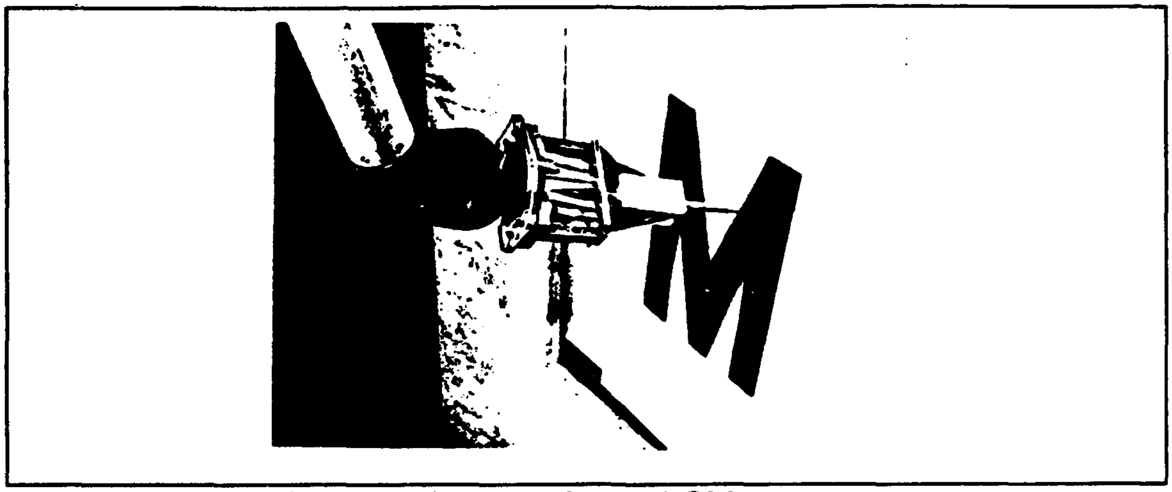


**Figure 12. Telemanipulator Probe and Object.**

Deliberating about the effects of friction produced by the arm and the taskboard over the object identification process professor Driels and Spain stated:

> If one considers the general strategy of probing a letter, the operator attempts to conceptualize the location and orientation of the taskboard and then tries to move the probe lightly over the board until contact with the letter is made. Then, still minimizing the contact force between the probe and the taskboard, the probe is traced around the letter building up individual primitives into features and spatially mapping them into a recognizable object. (Driels & Spain, 1990, p. 876)

This leads to the perception that haptic proprioceptive search strategies are performed in a serial or sequential manner as is also the case in the foveal search pattern.

## E. SECONDARY OBJECTIVE

Based on the similarity of the response on both cases of visual restricted vision with only the foveal component and the haptic proprioceptive alone, in which serial search patterns are exposed, a second objective emerges in which the correlation between those two components of the visual and haptic systems will be explored.

The 26 letters of the alphabet were chosen as the object set for several reasons. It is a set well known and familiar for any subject thus this will avoid a prorogated phase of training but at the same time they will still retain the particularity of the unknown because models of fine details of the font used can only be built up during the construction phase. Another important reason is due to the fact that the subject will perform categorization of the objects instead of solely pattern apprehension.

> One reason for caution in generalizing results from studies with artificial objects or raised graphics displays to haptic performa..ce as a whole is that such studies generally require pattern "apprehension"-obtaining information about volumetric, topographical, and other attributes of the stimuli-as opposed to categorization. (Klatzky, Lederman & Metzger, 1985, p. 299)

Experiments of tactual exploration of raised two-dimensional displays like maps of South America, has been implemented in which the subjects failed to recognize them. This leads to the underestimation of the haptic capacity since the object set chosen was a replica of cues dictated by the original visual model and not by haptic stimuli. By choosing the alphabet as the object set it is believed that the haptic system will expose its abilities for object identification.

## F. SEARCH DESCRIPTORS

If a person identifies and recognizes objects by assembling a pattern of feature sequences we have to define which are those primitive components for which an observer focuses its attention, and how they are summed or integrated. Noton and Stark found that when subjects are freely allowed to view pictures that display line drawings, the fixation points tended to cluster around features such as angles and sharp curves, these being the ones that attract most of the subject's attention. Fred Atneave III of the University of Oregon, 1954, showed this hypothesis to be true by selecting 38 features of angles or greatest curvatures from a picture of a sleeping cat an joined them by straight lines, the result is still recognizable as shown in Figure 13.

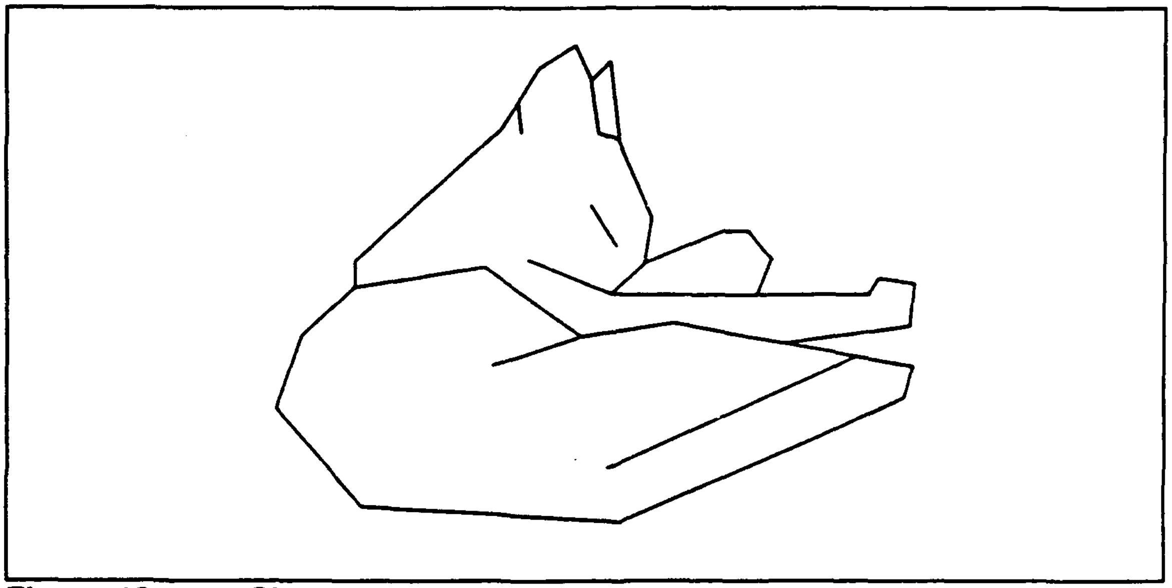


**Figure 13. Sleeping Cat.**

In the present research a code circle will be used to represent the different features inspected by the subject during the exploration experiments and the sequence in which they were fixated. The different experiments developed and analyzed will be explained in detail in the next chapter, but basically a code circle will be constructed for each of the letters that were explored by the subject. Circumscribed and around the circle, lower case letters will be displayed which will represent each of the features that characterizes the sample letters. The features are classified according to angles, curves or straight lines. The sequence that the subject follows, is recorded in strings, taking on account if the contact with the features has been done in a scanpath manner, sequentially or if the search pattern has been interrupted at any point to be renewed in a different one. This is also shown in a string representation with separated letters for sequence interruption and renewal and sequence of letters according to the continued search strategy.

The arrows identify the first and last explored features designated according to their pointing direction. Interrupted dash lines represent a separation of the probe from the letter object and the new point of contact during the sequence. Lines that cross the circle resembles a scanpath or parallel pattern as opposed to the serial or sequential which will be shown as continuous external lines to the circle and making contact points in those features explored by the subject. Detailed transposition of the information is then available with the intent of obtaining factual results of human search patterns for the purpose of developing a basis for extended analysis. In the following example as shown in Figure 14, the letter object "A" has been labeled according to its different features with lower case letters starting from the left lower angle and following a clockwise order as shown in a). The internal triangular pocket has also been labeled following the sequence of the external peripheral features. The order in which these features were

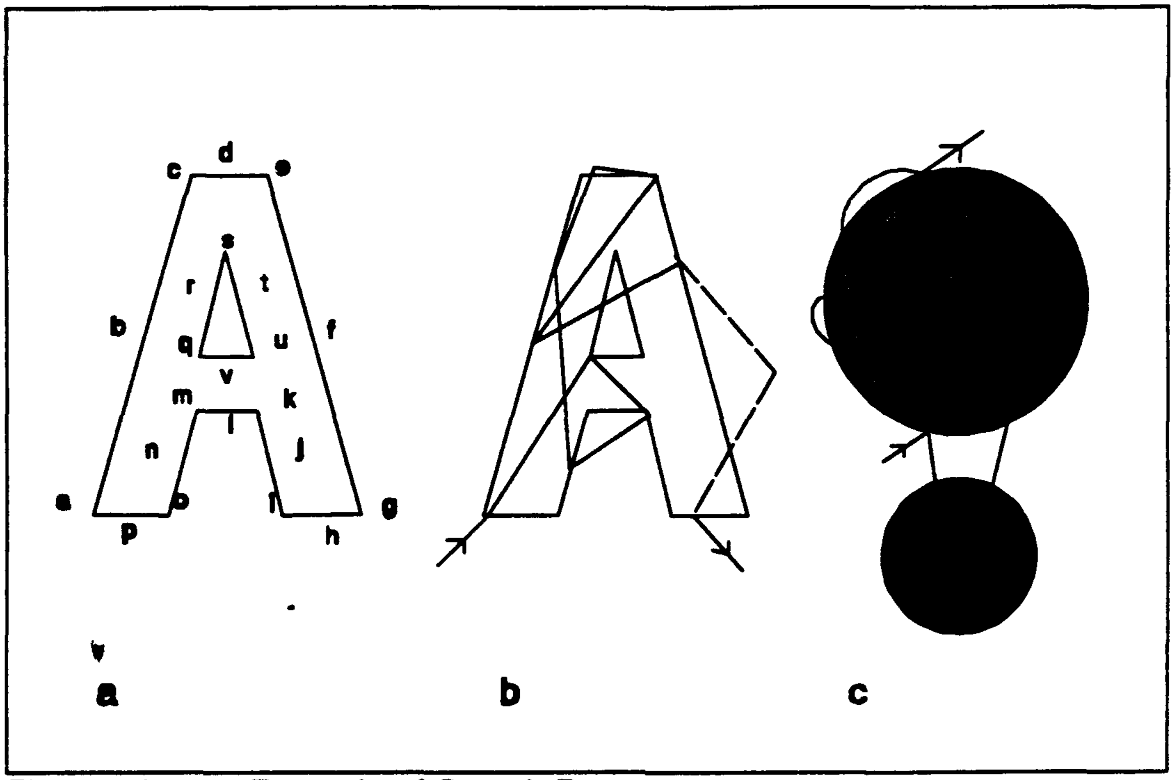



**Figure 14. Example of Search Pattern.**

inspected by a subject are represented in b) by straight lines. The first fixated feature was then the corresponding to the lower case letter "a" noted by a pointing arrow, followed in the sequence by the left lower angle of the internal pocket designated by letter "q", proceeding to the angle designated by the letter "k", then to the straight edge labeled "n", following to the parallel edge "b", then going up to the side "d" and upper right angle "e", coming back to the edge "b", then to the nonparallel edge designated "f". At this last point, the subject separated its fixation from the object and its therefore represented by a discontinuous line. After this, the fixation occurs at the lower right edge "h" and finalizes at this point the search, which is denoted by an outpointing arrow. The code circles in c), resemble the sequence of fixations of the exploratory pattern employed by the subject. The lower case letters represent the homologous features represented in a). A second code circle will also be employed for those particular features that unequivocally identify a letter such like the cusp in the letter "B", or for the internal pocket of the letter "A", and only when the subject has explicitly expressed its intention to verify them as a mean of achieving a positive identification of the object. The first step for processing the data of the search modes employed by the operators during the experiments, is to represent the sequence of explored features in a string. The ratio of the number of sequential feature search over the total number of explored features minus one, offer the measure of the percentage of serial search strategy employed:

Sr = Sequential Ratio

M = Number of Sequential Feature Search

N = Number of Features

$$S_r = \frac{M}{N-1}$$

In the example, out of the ten fixated features only one mode between "d" and "e" appeared to be sequential, therefore the sequential ratio equals to:

$$S_r = \frac{1}{10-1} = 11.11\%$$

Note in the string that the blank space between "f" and "h" represents the separation of the fixation of the object during the search mode example. The following string $S_t$ represents the sequence in which the feature were explored: $S_t$ = [aqknbdebf h].

## G. SIMULATED FOVEAL VISUAL SEARCH

In order to be able to correlate the foveal and haptic proprioceptive components and to compensate for the lack of a computerized visual system that would automatically record the fixation points of the foveal visual search patterns, a computer program was developed in order to simulate the foveal component. It was done by displaying a randomly selected and oriented letter similar to those used in the haptic experiments, over a television screen. The letter would be unable to be seen except from the content of a small window and whose position is controlled by the operator by using a pointing device such as a joystick, this is shown in Figure 15. The different positions originated from the subjects search strategies, would automatically be recorded and thus supplying the possibility to replay them with the complete object being shown for analyzing the search patterns exposed by the subject. This would simulate the experiments performed by Watanabe in the elimination of the peripheral visual region therefore compelling the observer to use only the foveal component of vision.

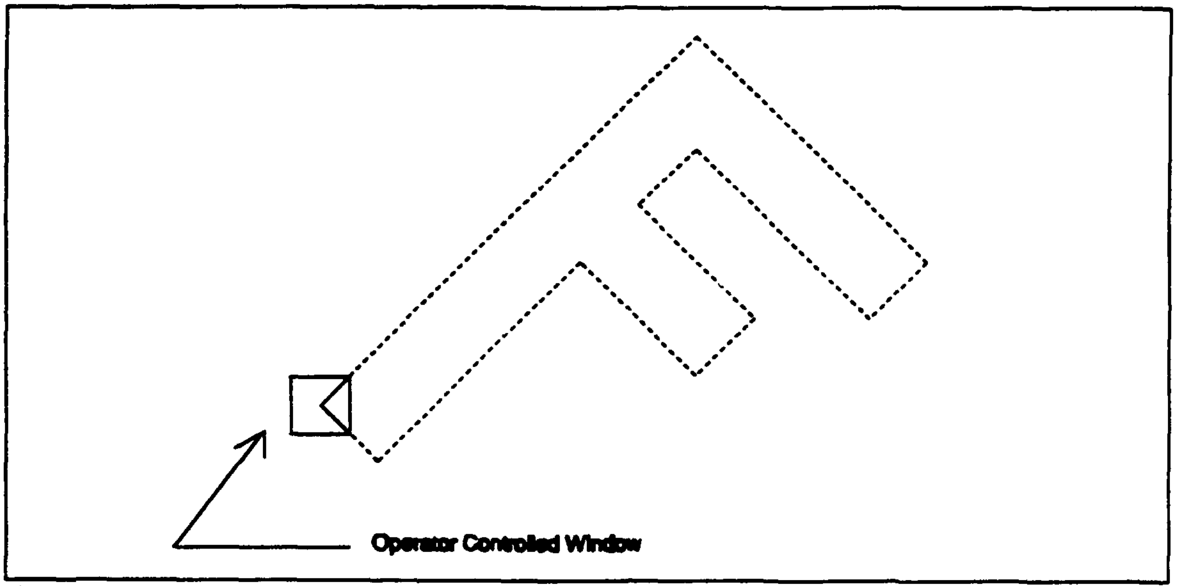



**Figure 15. Simulated Foveal Visual Search.**

## III. EXPERIMENTAL DEVELOPMENT

### A. SUBJECT CONDITIONAL ENVIRONMENT

Subjects were submitted to previous training in the handling and control of the telemanipulator in the haptic probing experiments as well as with the joystick for the simulated foveal case. This was required because that such devices are rather cumbersome to move and physical effort is demanded as with the telemanipulator, or are very sensitive to small displacements of the fingers or hands as in the latter case. Since the goal is to obtain the natural response of human strategies for identifying the related object, the least influenced or disturbed performance of the subject due to external factors such as concentrating on how to operate the tools, was an required condition. General comments about identified features or perception of the object and its orientation, were requested of the subject at any stage of the trial run. The experimental subject told of the importance of attaining a positive identification of the object rather than minimal time spent or the utilization of guessing techniques. Explanations of the objective of the experiments were not given in order not to precondition their natural search pattern for identification of the object. The training phase was considered achieved according to performance levels in positive identification but not in time to identify. This can be shown in a curve labeled by the number of trials versus percentage of correct identification as in Figure 16. This means that for a given subject,

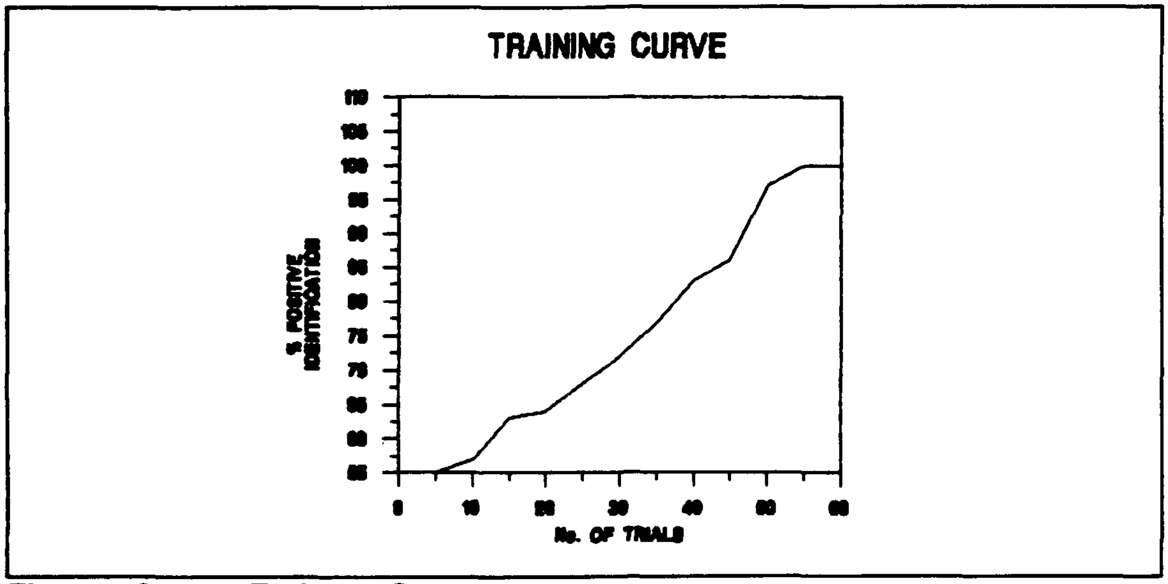



**Figure 16. Training Curve.**

training time was not limited but rather performance levels were defined as the minimum conditions for actually running the trails and gathering data.

For the proprioceptic haptic experiments, a telemanipulator similar to that used by Professor Driels and Spain was employed. In this type cf a device, force reflection is obtained through the pistol type grip handle and through cables that operate each of the pinions that conform the degrees of freedom of the telemanipulator. The probe used was a 1/4 inch diameter and 2 inch long metallic and plastic rod that slides over a plastic covered taskboard in order to diminish frictional components. The operator was unable to watch either the probe nor his hand displacements since he wore masked goggles; a curtain between him and the taskboard prevented the visual recognition between trials of the next object. The configuration is shown in Figure 17.

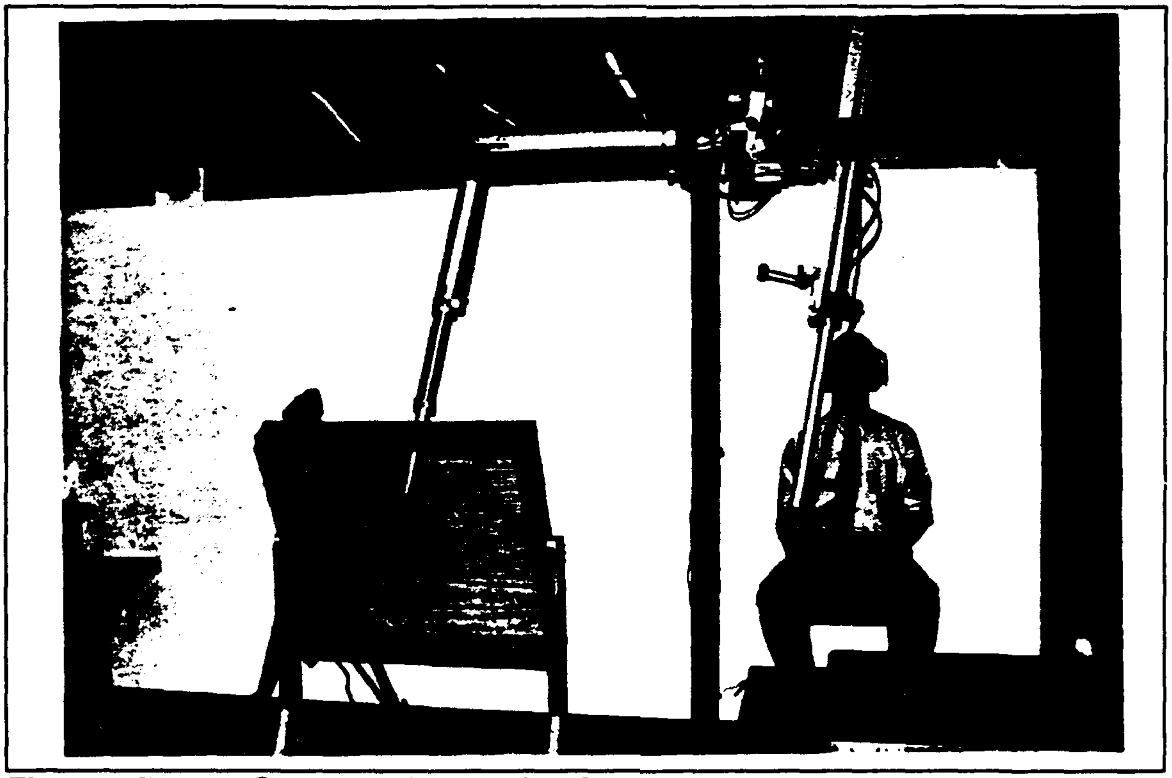


**Figure 17. Operator Performing Experiment.**

Figure 18 shows a detail of the manipulator probe in touch with the object.

For the Simulated Foveal Experiments an AT IBM computer was used with a joystick as a pointing device for controlling the view window over the screen. The window size is of 1/8 inch per side which resembles an equivalent area of foveal visual component at a normal distance to the screen from where the subject is operating the device. For the Full Visual Experiments, the subject viewed a letter displayed over a monitor screen without any type of conditions or constraints.

**Figure 18. Detail of Manipulator Probing.**

## B. CORRELATION BETWEEN FOVEAL VISUAL SEARCH AND SIMULATED FOVEAL VISUAL SEARCH EXPERIMENTS

Two analogous objects were examined in order to establish the similitude between search patterns used by subjects employing only the visual foveal component as in Dr. Watanabe's experiments and simulated foveal visual search using the computer. In the first case as shown in Figure 19, the greek letter beta was used and the results show a very graphic sequential search pattern during the recognition phase of the object.

After the whole letter has been scrutinized, a shift to parallel search pattern is observed during what apparently is a confirmation of the identification of the

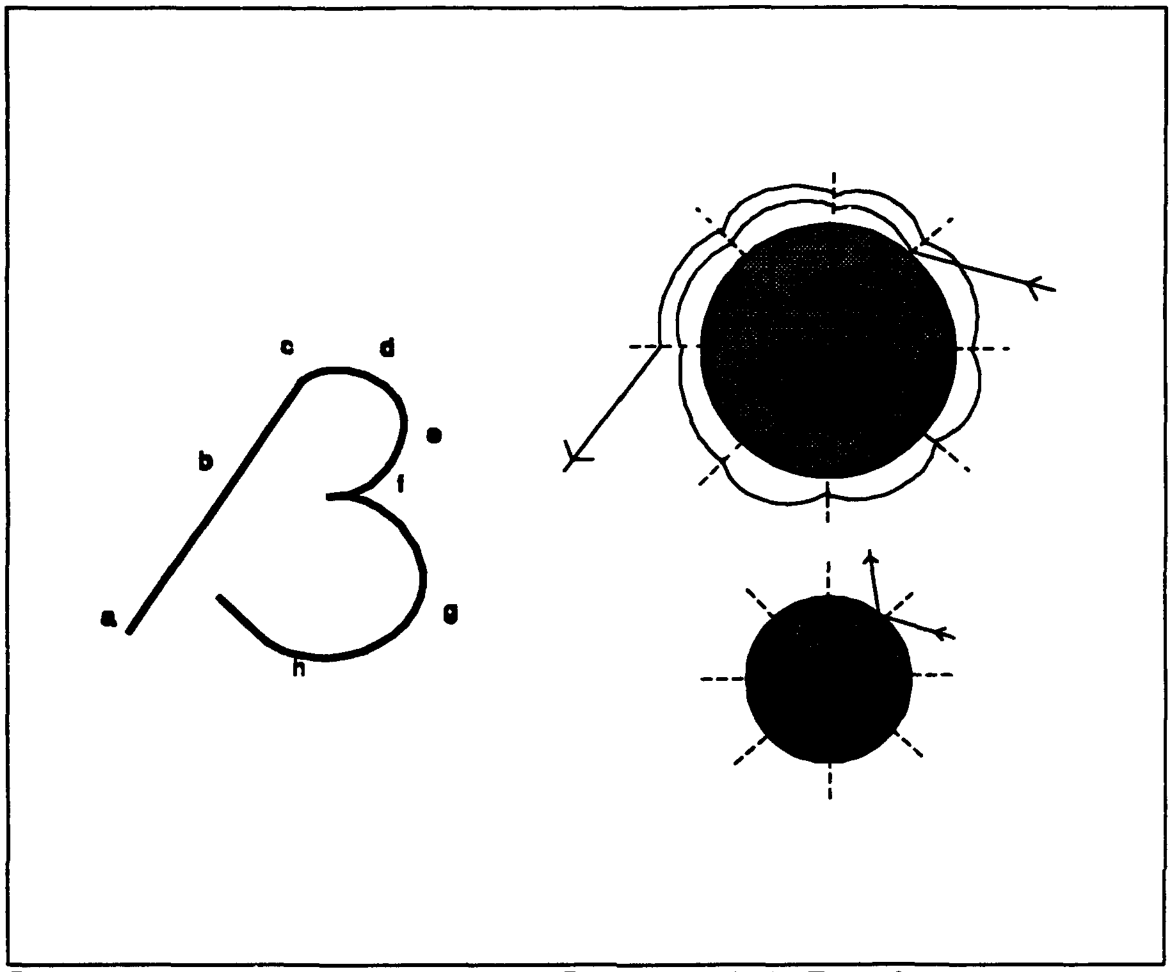



**Figure 19. Letter Beta Used in Dr. Watanabe's Experiment.**

object. The sequential ratio for this case equals:

$$S_r = \frac{11}{15-1} = 78.57\%$$

The following string represents the sequence in which the features were explored:

$S_t$ = [fedcbahgfedcfcf].

The letter "B" was used for the simulation of foveal visual search, as shown in Figure 20. It was also possible to observe results which depict a very close sequential pattern. This leads to support the assumption that the S.F.V.S. is a fairly acceptable method to substitute the visual foveal component allowing then to use it for the development of experiments using the foveal visual component. The sequential ratio for this case equals:

$$S_r = \frac{15}{20-1} = 78.95\%$$

The following string resembles the search pattern employed:

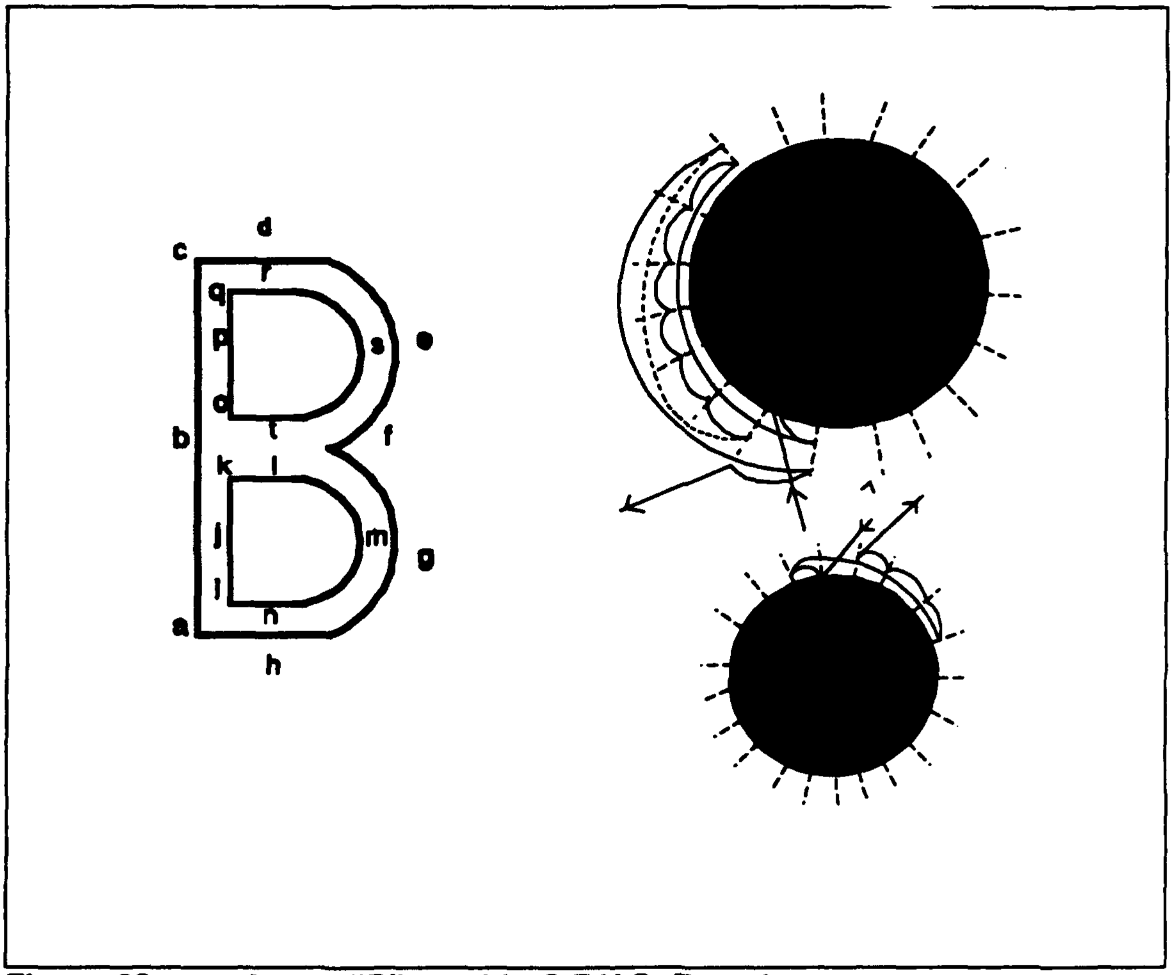



**Figure 20. Letter "B" used in S.F.V.S. Experiment.**

$S_t$ = [bjbahgfed cb hab jinmlk].

The same letter "B" was used during a Full Visual experiment, shown in Figure 21, in which the fixation points of the observer's foveas were plotted. It can be observed the high degree of parallel search employed and how the saccades are following a scanpath strategy.

## C. EXPLANATION OF EXPERIMENTS

For the three modes of experiments, simulated foveal visual search (S.F.V.S.), haptic proprioceptive and full visual search, the same object set was employed retaining their characteristics of fonts, size and angle of rotation. In the first two cases the time was recorded from the moment in which the object was contacted until it was positively identified. For full visual experiments, fixed time of recognition was measured.

### 1. Simulated Foveal Visual Search - S.F.V.S.

For this experiment the subject uses a pointing device in order to control a rectangular view window. Over the video screen a random selected and oriented letter is displayed but its lines and features be observable only in the small window, the rest of the screen is blank. The subject has then to move the window over the screen in order to make an initial visual contact with any part of the letter and its eventual identification. When the initial contact is achieved, time is registered in order to maintain a record about the search strategy phases. Any verbal comment that the subject may relate about his perception of the features

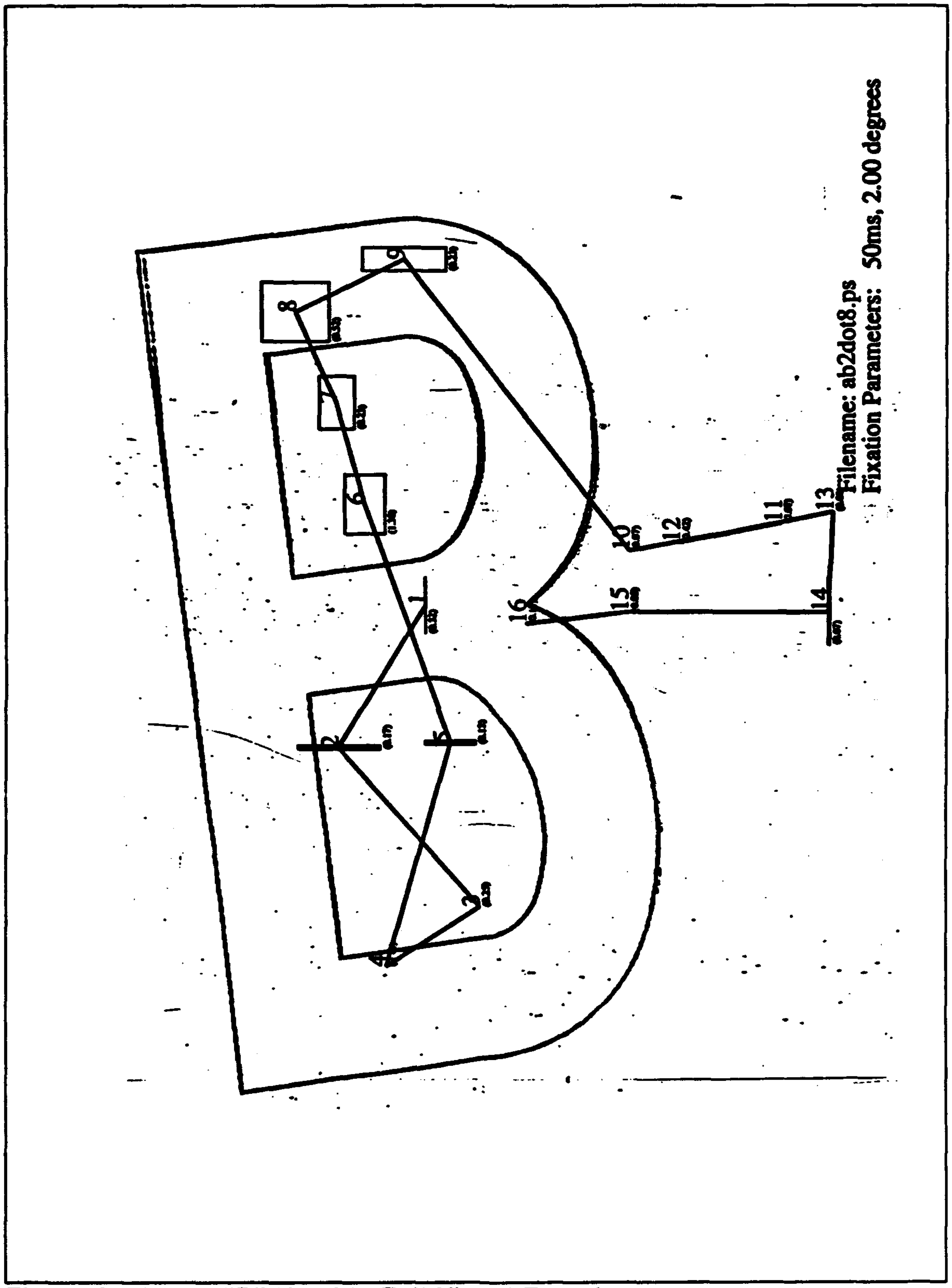



**Figure 21. Letter "B" Used in Full Visual Experiment.**

spatial distribution, characteristics, orientation or the identification of the object itself are registered. The verbal comments about the evolution of the experiment are not imposed to the subject in order not to subordinate his spontaneous response, but they are encouraged to do so since in some instances these comments corroborate the actual search modes. Although haptic proprioceptive component is present in this experiment, due to the use of fingers or hand in moving the pointing device, its scale compared to that of the window displacement over the screen are significantly different, therefore not considered as a predominant contributing component. The operator does not receive visual feedback from the hand movements for obvious reasons of his gaze concentration over the screen. Time spent in the identification procedures was never a constraint because positive identification was emphasized of the object instead of speed.

### 2. Haptic Proprioceptive

A CRL force reflecting unit of the terminus type that allows the operator to sense the force at the handle, is used for this experiment (Driels & Spain, 1990, p. 874). The subject is able to grasp a pistol-type handle with one or both hands and has freedom to move fingers, wrist, elbows and arms for obtaining haptic feedback when operating the telemanipulator. The eyes are masked to avoid visual detection of the movement of these extremities in order to superordinate the haptic system. A curtain that separates the operator from the taskboard, prevents the subject from viewing the selected object to be explored. The use of earplugs mask any audible cue resulting from frictional forces between the probe and the taskboard as it is displaced or by tapping it against the objects lateral sides. The letters used are wooden made of 1 inch of thickness and 6 inches of length with their borders covered with metallic tape which diminished frictional forces between the probe and the letter although it also has the double purpose of allowing electrical ground when required for other experiments. The probe is a metal rod of 2 inches of length with a plastic rounded tip which offers sufficient stiffness and low frictional profile. This is required for reflecting contact forces between the probe and the object with minimum disturbances from contact forces with the taskboard which is also made of plastic. Verbal comments were encouraged as in the S.F.V.S. case and were recorded together with the filming of the experimental trials using a television camera. The subject was asked to use the telemanipulator for identifying the random selected and oriented object, and he did so by contacting the letter with the probe and exploring its features by means of this contact. The reflected force is the stimuli that indicated the contact with the object and the haptic proprioceptive component what permits the apprehension of its features.

### 3. Full Vision

Experiments for full visual search patterns were held in the laboratories of the Departments of Physiological Optics, Engineering Science and Neurology at the University of California, Berkeley. These laboratories are presided over by Professor Lawrence Stark whose affability and kindness permitted this development.

The same set of objects presenting the same orientation were used. The subject was placed in front of a video monitor with a separation from it of about twenty inches and his visual angle was scaled to the size of the screen by the use of appropriate software. The different letters were presented on the monitor for a lapse of five seconds, time during which, the fixation points of the fovea over the letter's features were recorded. After processing the data, it is possible to superimpose the order and location of the scanpath exhibited during the object exploration. In this experiment the subject is employing both the peripheral and foveal component of the visual sense and responds to the object stimuli in a natural manner. No condition is imposed over the subject during he test but only to gaze at the presented object.

## D. EXPERIMENTAL RESULTS

In order to process the experimental data and represent it in a format that can be easily interpreted, strings and code circles are used. For the S.F.V.S a computer program permits to reproduce the actual search patterns used by the operator and at the same time allowing the current letter to be viewed superimposing the path of the view window over it. The speed of the window displacement can be controlled for purposes of reconstructing the search strategy and building up the string which represents it. For the haptic experiments the video film provides the means for editing and extracting the desired information. Each letter object is labelled with lower case letters at each straight line, angle or curve.

The features will represent therefore, the order in which the operator explores each of the objects features. Blank spaces between string letters represent a deliberately separation of contact from the object and a renewal of the search strategy at a feature represented by the first letter of the next string segment. The double asterisk separates the search sequence from the moment in which the operator specifically expresses with a verbal comment, that he is shifting the search mode in order to verify a particular characteristic of the letter in order to unequivocally identify it. The utilization of strings to condense the exploratory search strategies illustrates an advantage which is to permit the future utilization of computer string matching algorithm's in order to simulate human procedures of identification of objects. The strings are further represented as code circles for easiness in visualization the pathways of the search modes. Basically these are circles with the same lower case letters that identify the objects features, circumscribed on them. The search pattern will be depicted with continuous external lines touching those lower case letters corresponding to features that has been explored,doing it starting from the inner part of the letter's corresponding radius to the outer part of it for sequential patterns. For parallel scanpaths, continuous lines will be used but intersecting the circle and pointing to the correspondent lower case letters and follow an opposite direction along the radius from that of the serial case, for increasing number of sequences. When the subject has deliberately halted the search and removed the probe from the object to eventually reassume it at a different feature, this action is represented with dotted lines. When a verbal comment supports the fact that the subject has shifted his exploratory procedures to a confirmation phase, a second code circle is used. This phase is one in which the object has been identified but a particular feature of the object, like the cusp of the letter "B" or inside pockets like in the letter "A", is being searched for final confirmation. The second code circle represents this phase and is depicted using the same conventions. The latter procedure is applied only to S.F.V.S. and Haptic data since for the Full Vision experiments the software employed generates a print with the reconstruction of the search patterns. Examples of both cases, S.F.V.S and Haptic, are detailed in Figures 21, 22 and 23. The sequential ratio for S.F.V.S case equals to:

$$S_r = \frac{34}{49-1} = 70.83\%$$

The following string represents the sequence:

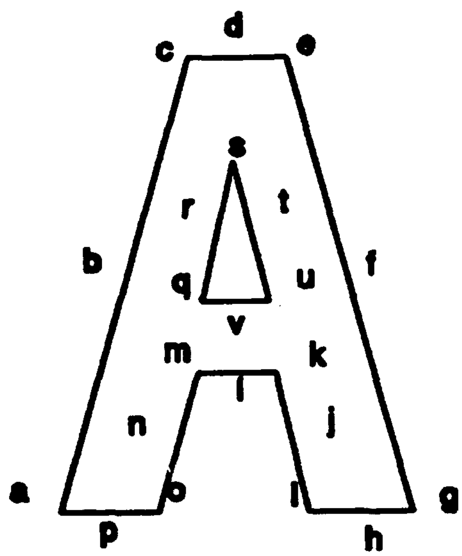
$S_t$=[ljklm pb cde bapbponmlkjkjkjihf b dfb**srstuvrstsrvqrstr].

The sequential ratio for the Haptic case equals to:

$$S_r = \frac{55}{63-1} = 88.71\%$$

The following string represents the sequence.

$S_t$=[bcbabapo po pn mnmlklm lklkjihihgfed fedcbfilmlkj lmnoponijkjkji**rstuv].




**S.F.V.S.**

[ijklm pb cde bapbponmlkjkjkji
hf b dfb**srstuvrstsrvqrstr]

**HAPTIC**

[bcbabapo po pn mnmlklm lklkj
ihlhgfed fedcbfilmlkj lmnoponl
jkjkji **rstuv ]

**Figure 22.** **Letter "A" Labeled and String Resulting from S.F.V.S. and Haptic Experiments.**

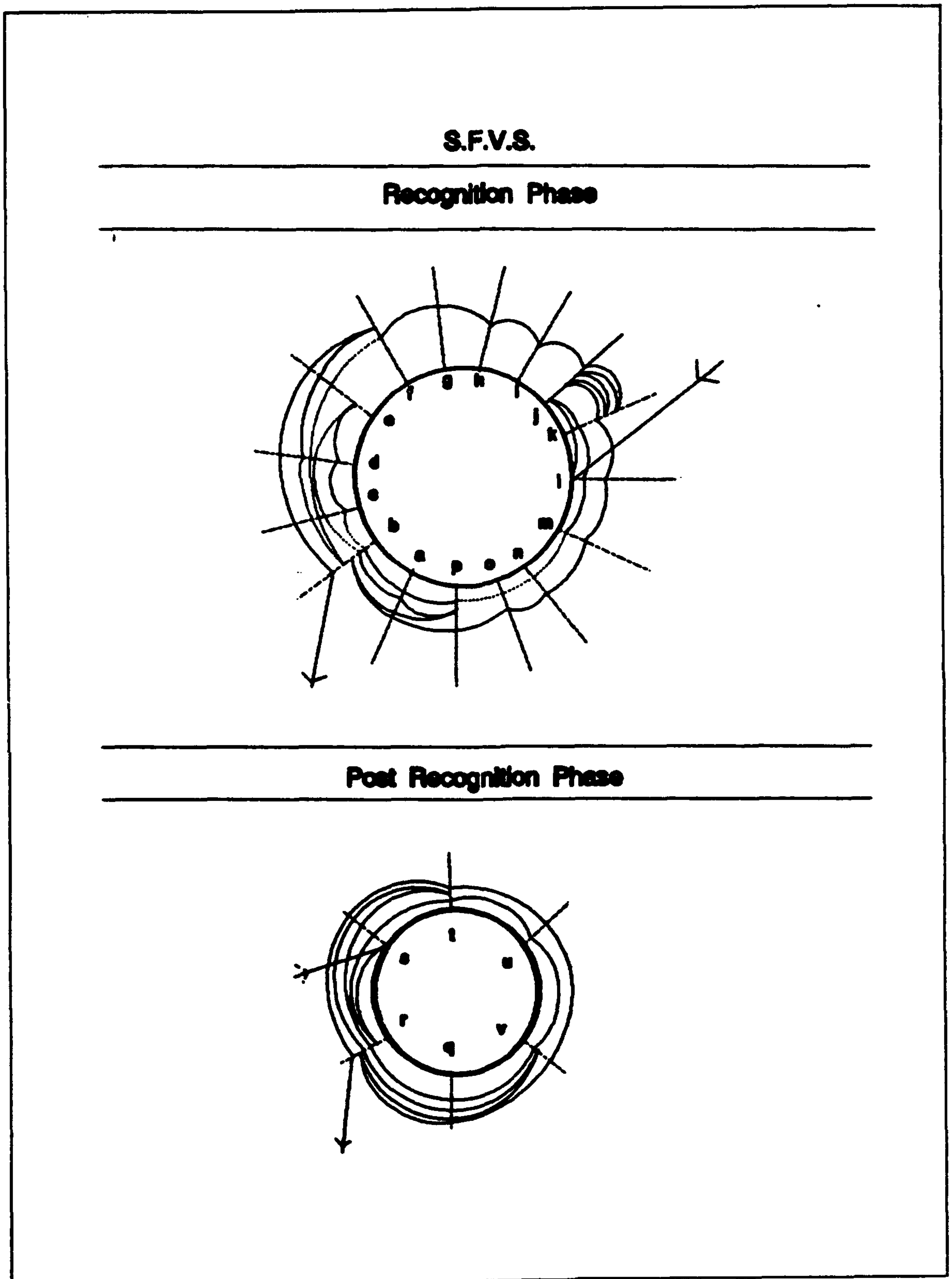



**Figure 23.** **Code Circle Representing S.F.V.S.**

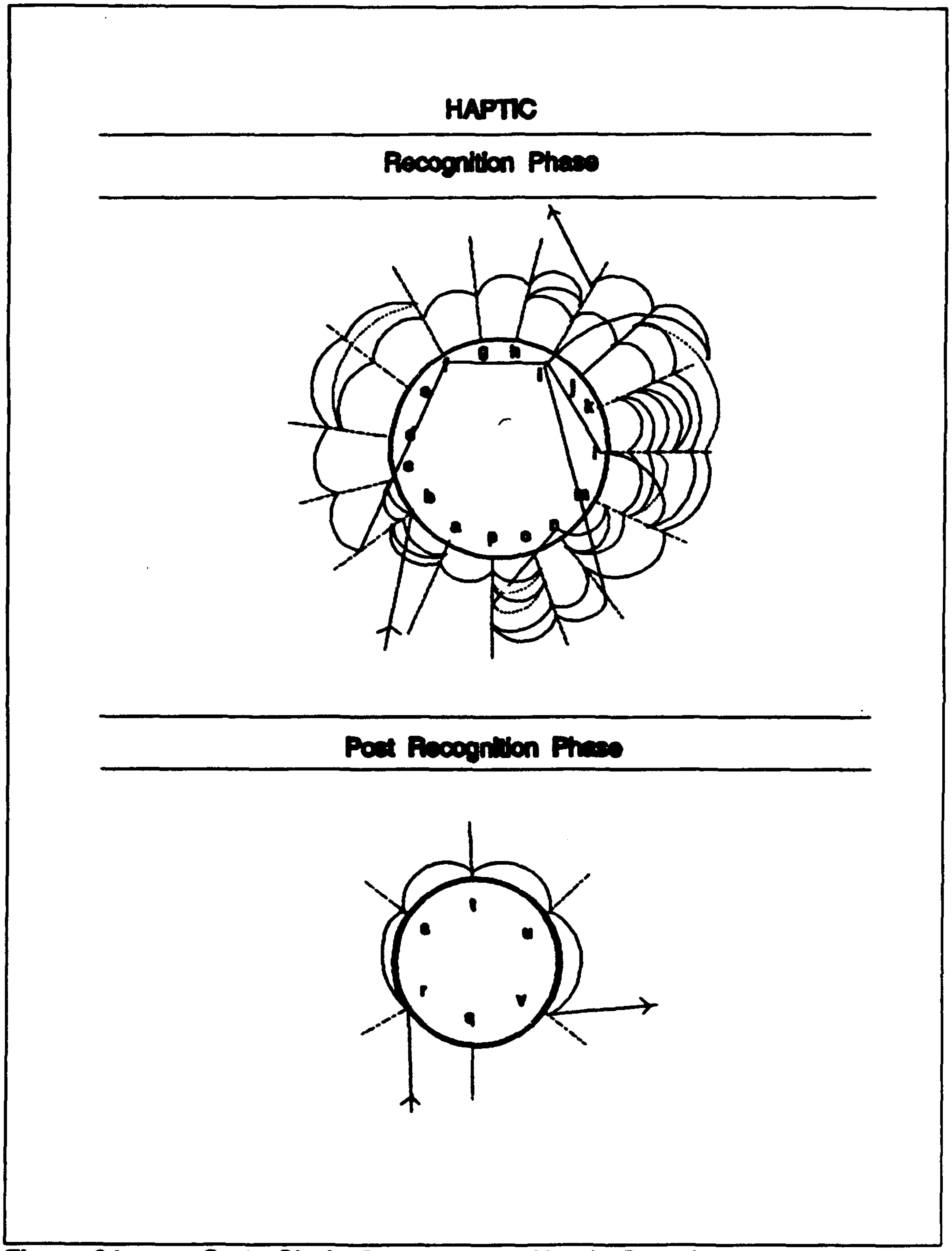



**Figure 24. Code Circle Representing Haptic Search.**

# IV. DISCUSSION

## A. TRAINING PHASE

The period of time considered as training was that in which the subject primarily dedicated his efforts in controlling the characteristics of either the telemanipulator or the pointing device. It was clear that the operator was concentrating on acquiring the ability for positioning the devices because of his verbal comments. This was also fully noticeable in the results of low percentage of successful identification as well as extended elapsed time for the object exploration. Although it depends heavily on the subject innate ability, an average time required for acquiring a fair level of skill in handling the telemanipulator can be estimated as ten non-consecutive hours and only five for the S.F.V.S.. The telemanipulator is more heavy and bulky, therefore requires dexterity and physical effort while the pointing device is easily movable and very sensitive to displacements thus demanding stability in hand movements. For continuous operation of either of the devices, subjects demonstrated effects of fatigue and tiredness as well as diminished concentration after an average time of one hour. During the first hour a well trained and relaxed operator achieved 98% object identification success in an average time of 2 minutes and 3 seconds. Since the time for obtaining an acceptable degree of dexterity is relatively low, no other techniques to reduce this time were explored, only the physical use of the devices in identifying different letters such that the operator could have a sense of feeling for the different features such as angles, straight line, curves and internal pockets or cavities.

## B. HAPTIC SEARCH

During the initial approach, before having a physical contact with the letter, the subject requires to establish a plane of reference with the taskboard. He does so by exerting normal forces with the probe and scanning the surface. This permits him to fix the handle position relative to the plane over which the object is attached. At the same time, by performing the scanning procedure over the taskboard, this will eventually obtain contact with the object, by the probe reflecting an applied lateral force. After detecting the presence of the object, the operator tends to increase the ratio of the lateral force applied to the object vice the normal force applied to the taskboard in order to avoid noise during the exploratory procedure. The probe is then displaced following edges and contours and generally revising the features by using a back and forth path. Angles were difficult to probe due to the inertial components of the telemanipulator which sometimes cause th operator to lose contact with the object. This results in a degradation of the mapping of the array of features already explored since most of the times the next visited point over the object was different from the departure point. This may explain the highly serial or sequential manner in which the operators performs during the exploratory search pattern. The rate at which a feature was probed, e.g.

an edge, seemed to increase after the feature was recognized and gave enough confidence to the operator as to use higher velocities of probing. The positive identification of a feature gives a base to use it as a reference in order to relate the spatial order of every other explored and identified feature. This provides the operator with the required information for the integration of the array of features and the eventual identification of the object and its orientation relative to the taskboard. In all of the tests, the orientation of the object was accurately established even if the object was not completely identified. Comments of the subjects infer that after recognizing some of the object features and their sequence, by exclusion, the set of letters that could provide those characteristics will be reduced. In this manner a positive identification will resultif enough features and their sequence were able to be integrated and matched to the internal memory representation of the object.

## C. FOVEAL SEARCH

The initial approach in this modality is the scanning of the screen up to the moment in which visual contact is achieved with any of the object's features. The pointing device as well as the screen are fixed relative to the horizontal plane therefore the operator does not requires to control this variable. The exploration of the object is done in an analogous way as the sequential manner exhibited during haptic exploration. The operator follows the lines and features of the object employing occasionally back and forth paths as if confirming the apprehension of the explored feature. Comments of the subjects confirm that when one of the features has been positively identified this one will serve as a reference from which subsequential identified features will be related in order to build up the spatial array of features. This infers that not only the particular sequence of identified features but also their relative orientation is essential for constructing the model and this latter is achieved in the referred mode. The operators tended to use the fingers more than the wrist to manipulate the pointing device arguing that better control over small displacements allowed fine detailed inspection of the object. Eventually a small percentage of scanpath type of response was observed in this type of experiment giving the basis to infer that the visual memory helped to better fixate the spatial distribution of the array allowing the operator to move from one feature to another one not adjacent. The ease of operation of the pointing device is another important factor that facilitates the precision in positioning it.

## D. RESULTS OF HAPTIC AND S.F.V.S.

The correlation between haptic and S.F.V.S. is evident as shown by the experimental results. In both modes the search pattern is developed in a consistent sequential manner being higher in the haptic probing, which has to appeal solely to the perception memory while in S.F.V.S. it is also supported by visual memory. In both cases the speed in which an object was identified depended strongly on which was the initial string of features identified. For example, if the cusp formed by the two external arcs of the letter "B" happened to be explored initially, that particular feature gave a strong information to the subject as to recognize the letter and produce a shift in the search pattern seeking for confirmation by exploring the two internal cavities of the "B". Both modes also exhibited the eventual need of revisiting the same features in a circular manner, for example, the letter X can be explored in a complete serial fashion having two or more circuits around the object before identifying it. This letter contains twenty four features according to the conventional labeling, leading this fact to suggest that the more features an object displays requires more times they have to be explored as to be able to retain in memory the order of the sequence. Also, the higher number of isolated opportunities in which an object has been explored, the faster it is identified because the construction phase of the model has consolidated expediting the recognition phase to take place. In S.F.V.S. the reference plane over which the object lies does not need to be perceived as in haptic search, but in both cases particular features of the object supplies the reference for spatially mapping the relative arrangement of the remaining features. In haptic probing, the back and forth path of the probe over the features is done in a much higher frequency than in the S.F.V.S. mode seemingly because the object contact sensing depends more on the rate at which it is perceived rather than the absolute level of the force itself. (Driels, 1991)

The verbal comments of the subjects were very similar in both modes of search and it was usual to hear comments of the following type:

'I think I am on the inside of some Letter' or 'I think it is an M but cannot tell from the sides if they are slanted or not which could be a W, let's check again.' or 'There it is what I am looking for, the inside pocket of an A, yes it is an A.' or 'it is a Y but I initially thought it was a K because of the slight angle of the side' or 'I am thinking it is an E...no, because it does not has another leg which then makes it an F.'

These comments give a strong basis to complement the actual search strategies observed in the video film as well in the computer program finding a highly similar pattern in the two modes. The total average of the sequential ratio for the haptic experiments equals to 94.6% and for the S.F.V.S. a result of 73.9% was achieved.

## E. COMPARISON OF HAPTIC AND S.F.V.S. WITH FULL VISUAL SEARCH

In opposition to this type of strategies, the full visual search is characterized by an initial random eye movement or scanpath over the object which is particular to the subject performing the viewing and unique for the given object explored. These classec scanpaths are characteristic of the search strategy observed for regular images. This scanpath is created during the construction phase of the visual model of the object and reproduced in a fairly high rate during recognition phases if the subject is submitted to view the object on different occasions. Figure 25 shows the comparison of results of the three modes. The peripheral component of the visual sense supplies information about the spatial distribution of the different features in a gross mode allowing the subject to direct his foveas to them in order to scrutinize them in fine detail. Vision also allows the observer to differentiate between directional light perceiving shadows produced by the object

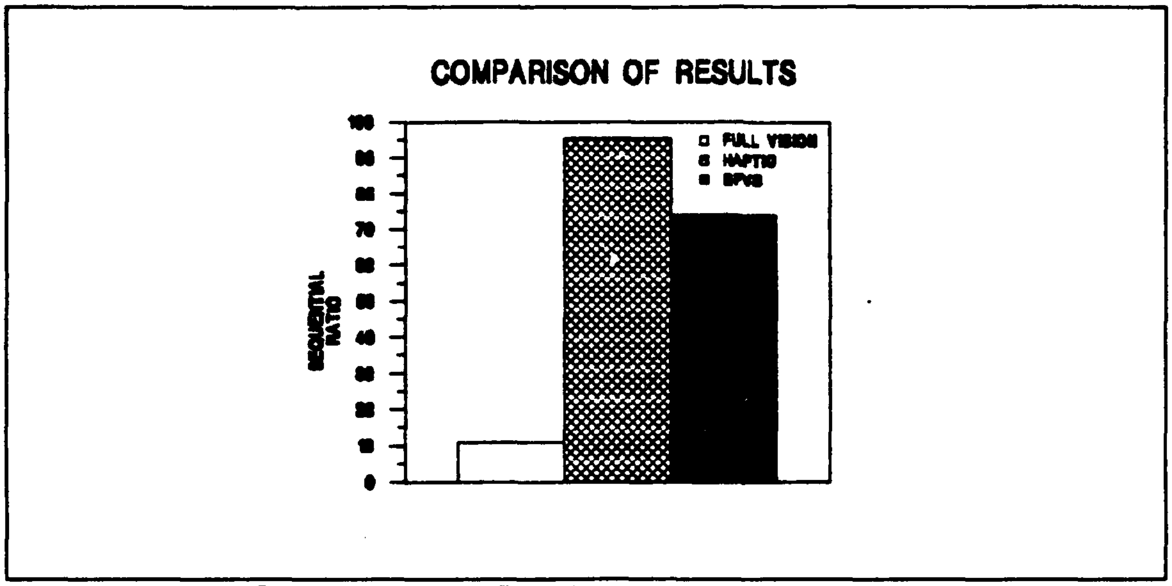



**Figure 25. Comparison of Results.**

therefore obtaining sense of depth which is a perception not encountered in S.F.V.S..

## F. EQUIVALENCE OF HAPTIC AND S.F.V.S.

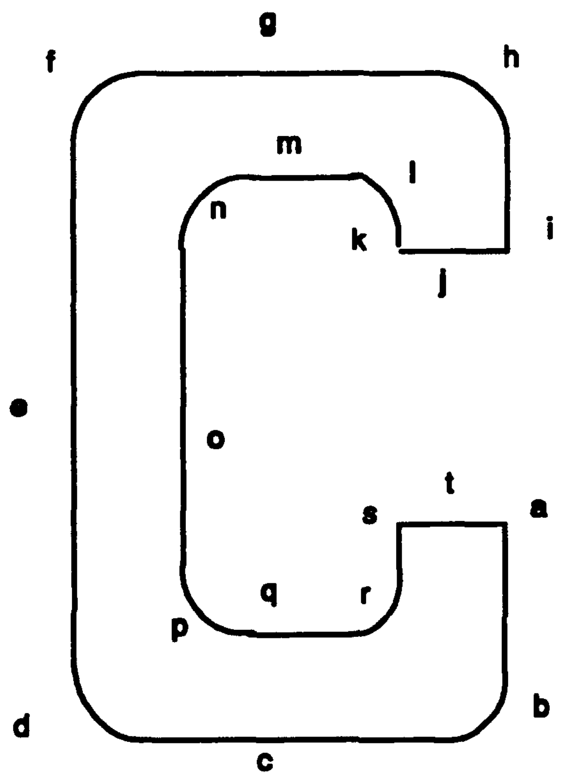
Based on the experimental results in which high correlation between haptic and foveal search patterns were encountered, it can be thought for a potential sensory substitution between both components. In the underwater scenario in which a diver has to perform tasks with visual limitations, the substitution of the foveal component by haptic probing can offer the operator the advantages of full visual perception. Under the natural constraints that an environment of this type imposes to a subject, the foveal visual component is in most cases diminished considerably due to lack of sufficient light and presence of other disturbances. The peripheral component though can be maintained, e.g. using artificial light, and by using mechanical devices for haptic probing, be complemented to approach full visual sensing to acceptable levels of performance.

# V. CONCLUSIONS

The fact that homologous results were obtained for Foveal Visual Search patterns and Simulated Foveal Visual Search, reflects the high similitude between both modes of search strategy. The sequential manner exhibited in both cases surpasses the 78% ratio which leads to the conclusion that Simulated Foveal Visual Search can be employed for experimental purposes replacing costly equipment required for monitoring the Foveal Visual Component. Analogous results of sequential search patterns with ratios higher than 80% were encountered in the Haptic proprioceptive experiments giving a basis to correlate it with the simulated Foveal Search trials. Both of these modes serve as substitutional components of the actual Foveal Vision. These results can eventually lead to the important utilization of the peripheral visual component in conjunction with the haptic proprioceptive sense. They can be employed profitably and advantageously in hazardous environments where expensive hardware would be required for achieving an approximate full visual capability. Under specific natural conditions of a disturbed environment, vision systems are not effective, as in the case of underwater scenarios with turbid waters. If blurred vision were available, haptic information could then complement it to achieve efficiencies approaching that of full vision. The present research achieved its goal of providing a reliable tool for exploring the search patterns used by humans when based on the Simulated

Foveal Component and methods for representing the way humans utilize the haptic proprioceptive system during object identification. It is expected that with these initial approach, lengthier analysis can be developed in order to better understand control of telepresence.

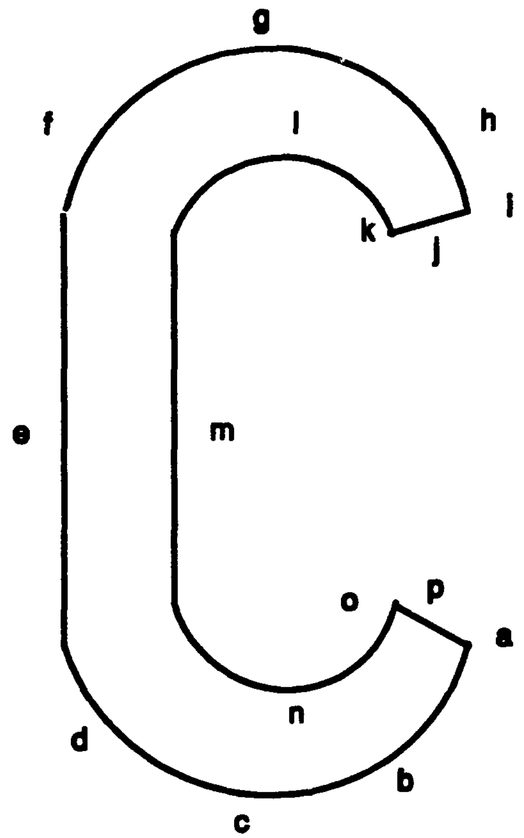
## APPENDIX A: EXPERIMENTAL RESULTS




S.F.V.S.

[kgngmnopqrstabcpf hg]

Sr = 61.11 %



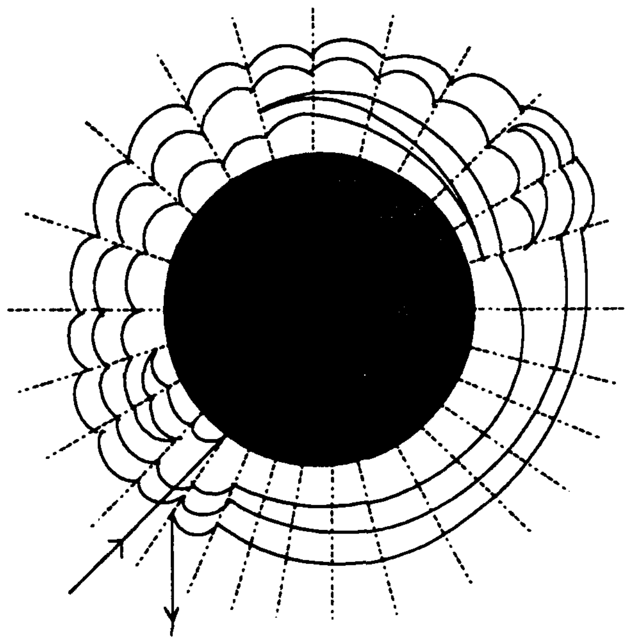

**HAPTIC**

[bcdedcbcdefghijpjpabcdefghijklmnopono pabcdefghijklmnopab]

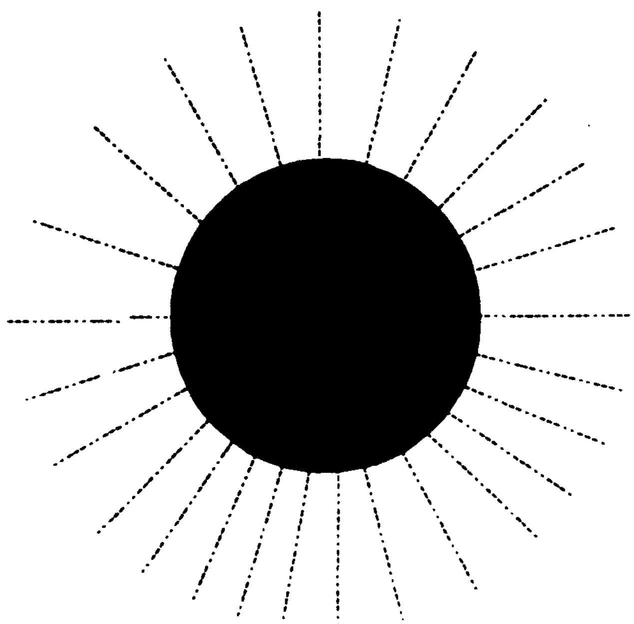
Sr = 94.55 %

| C | HAPTIC |
| --- | --- |

**Recognition Phase**

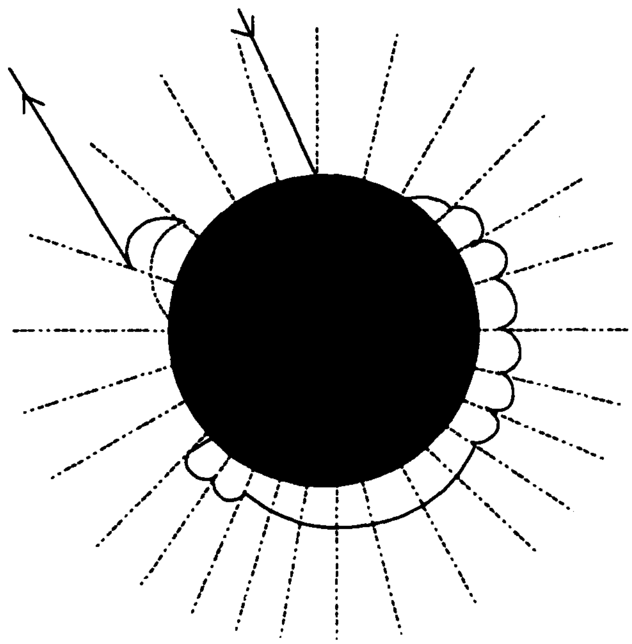


**Post Recognition Phase**

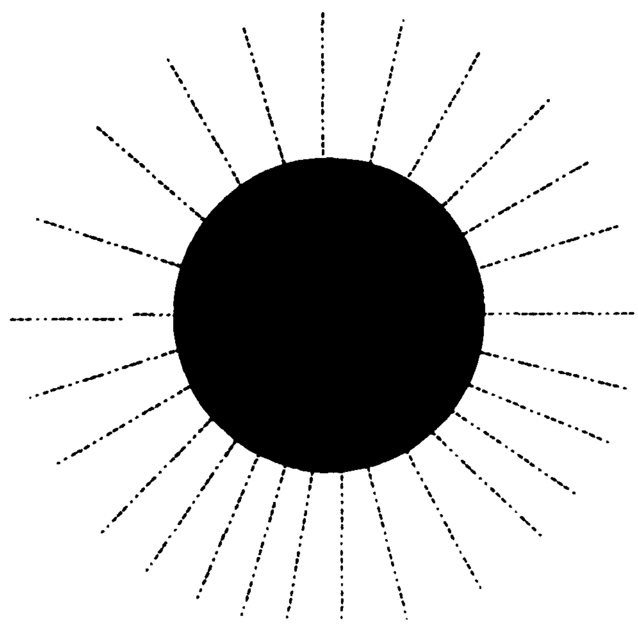


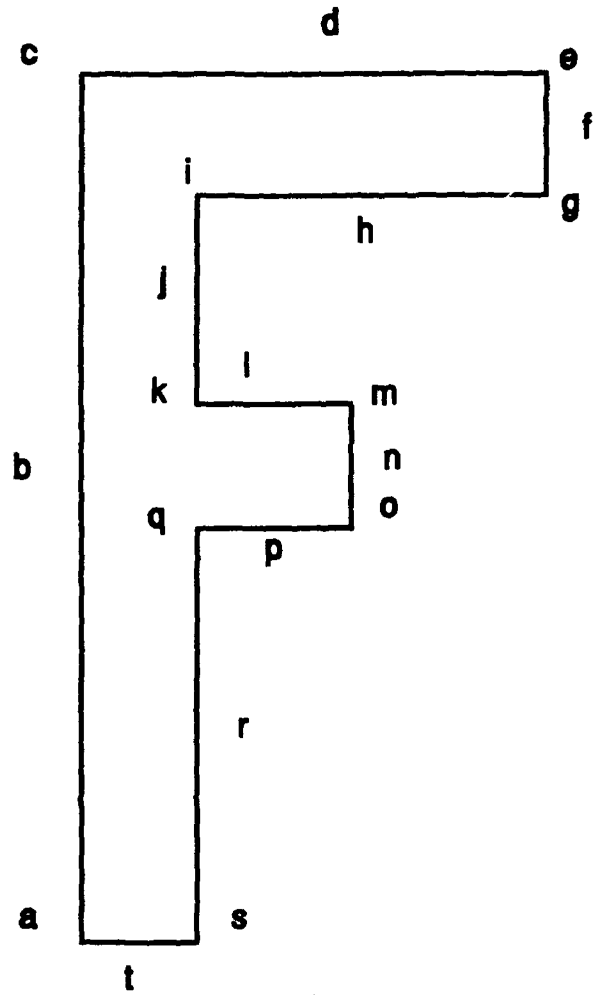
| C | S.F.V.S. |
| --- | --- |

**Recognition Phase**



**Post Recognition Phase**






S.F.V.S.

[ r b r s t a b c d e f d e d e f g d e f g h i j k j k l m n o l p q r s t a b ]

S r = 84.21 %

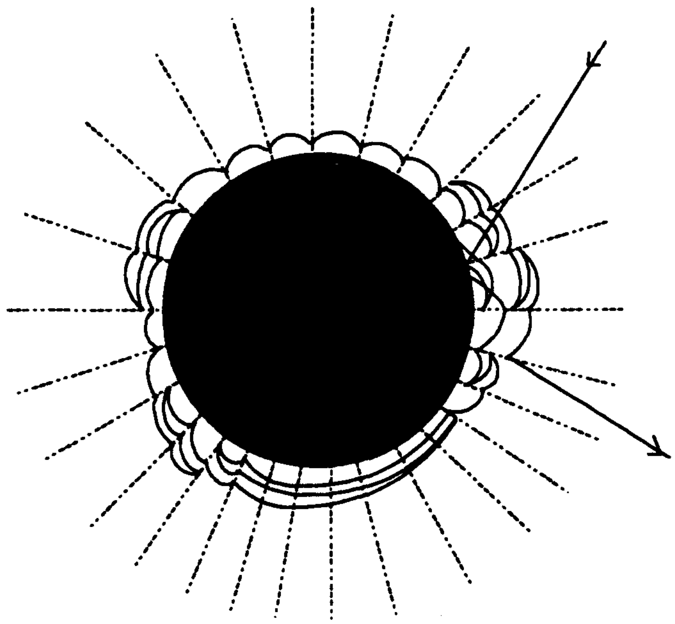
HAPTIC

[ p q p n p q r s r s t a b a t a b c d c b c d e f g h g f g h i j k l m n o p o n o p q p q r ** s t a b a t s r q p o n o p q p o n m l k j i h g f e d e f g h i h g f e d c b ]

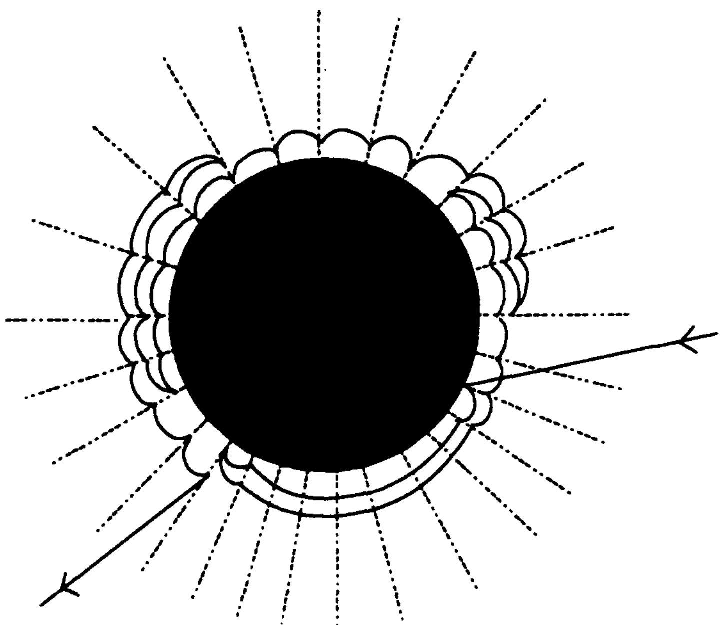
S r = 97.67 %

| F | HAPTIC |
|---|---|

**Recognition Phase**



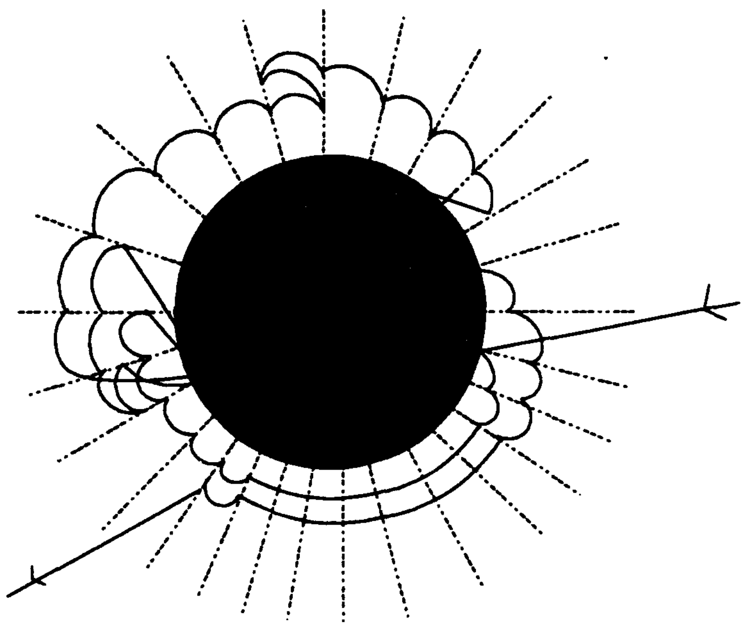
**Post Recognition Phase**



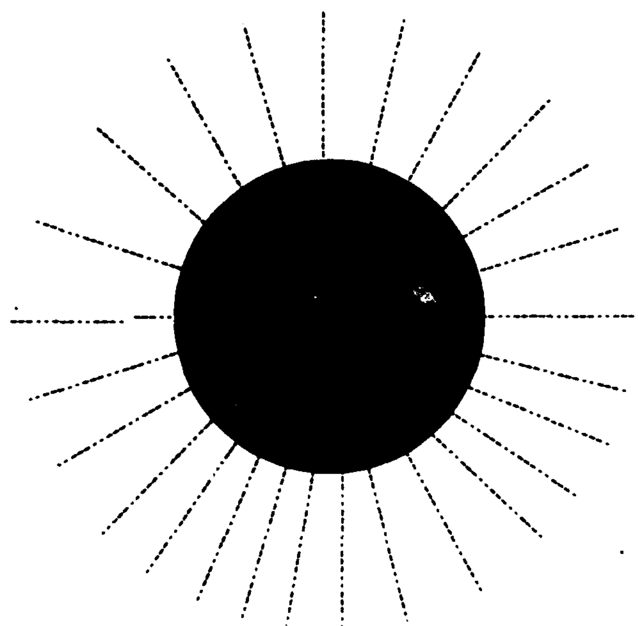
F

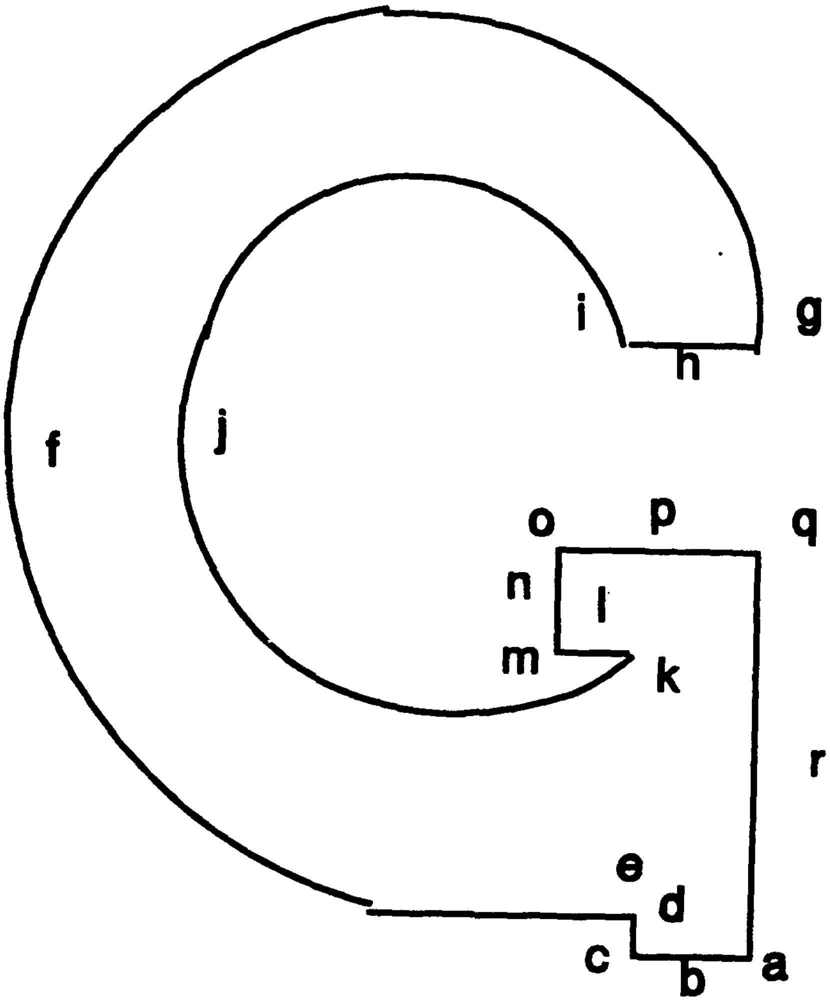
S.F.V.S.

Recognition Phase



Post Recognition Phase

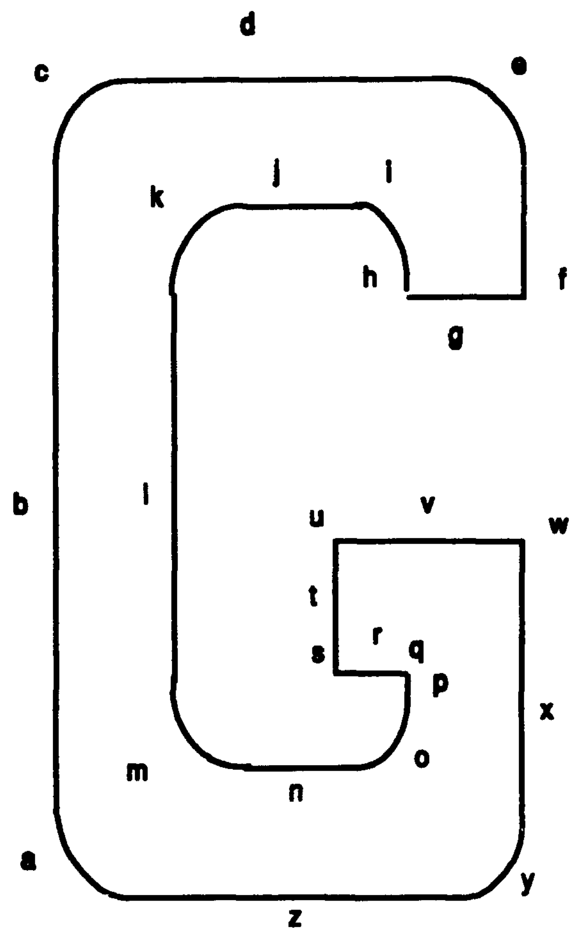





HAPTIC

[jkjkjklmlkjklmnopqrabfedcdefgonojklmlkl mnjihghihrqphphpqrabfedefgfedc ** barqp onmlklmr]

Sr = 86.42 %



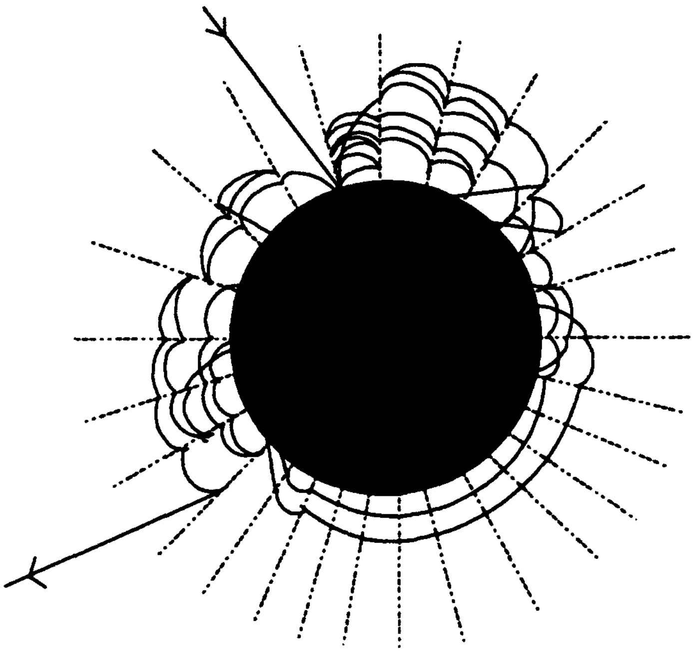

S.F.V.S.

[wxwvut sts nmnmlklkijkjihghgfgfefgfedkdcb yz yzyxwvxwv tuvut rsrsrqrsrqrsqsq on l fghijieg]

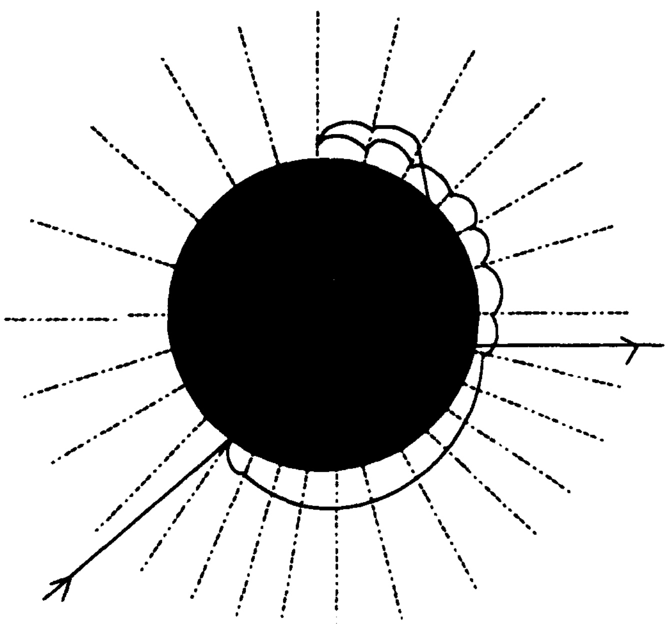
Sr = 80.25 %

| G | HAPTIC |
| --- | --- |

## Recognition Phase

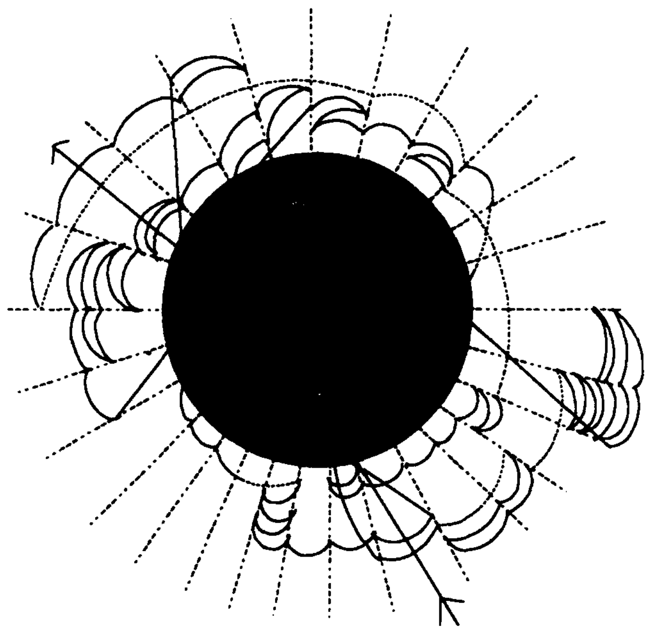


## Post Recognition Phase

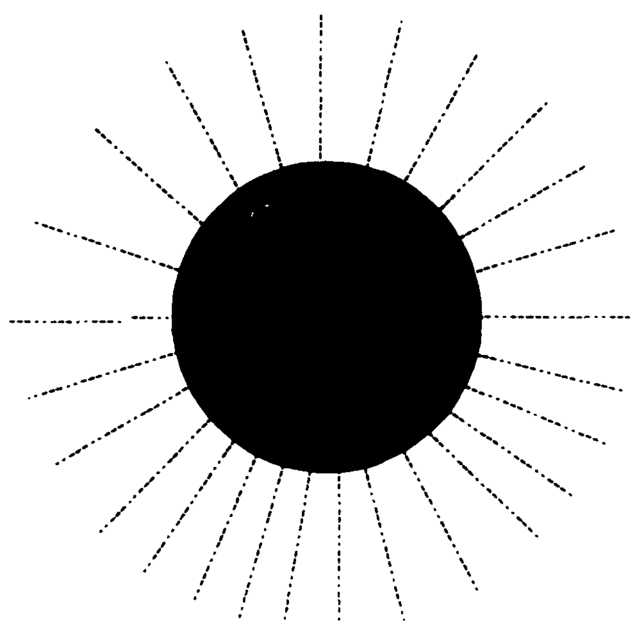


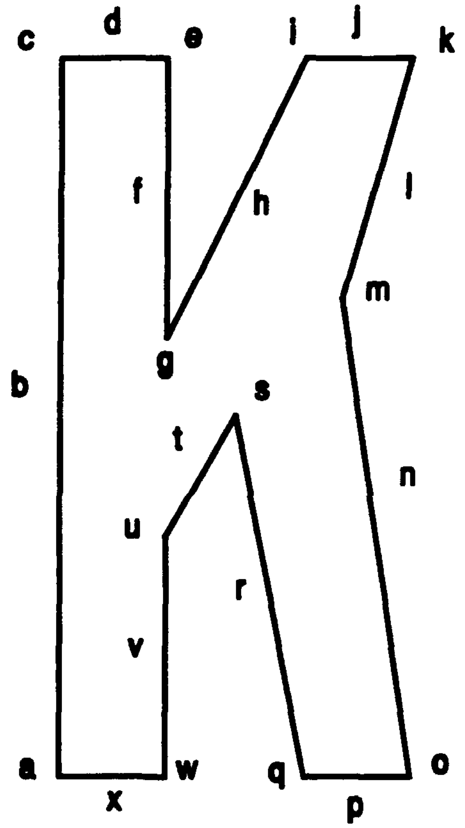
| G | S.F.V.S. |
| --- | --- |

**Recognition Phase**



**Post Recognition Phase**






S.F.V.S.

[fbcdefedefhghijklmnopqrqpqrstutsfhgts tuvwxab
]

Sr = 88.37 %

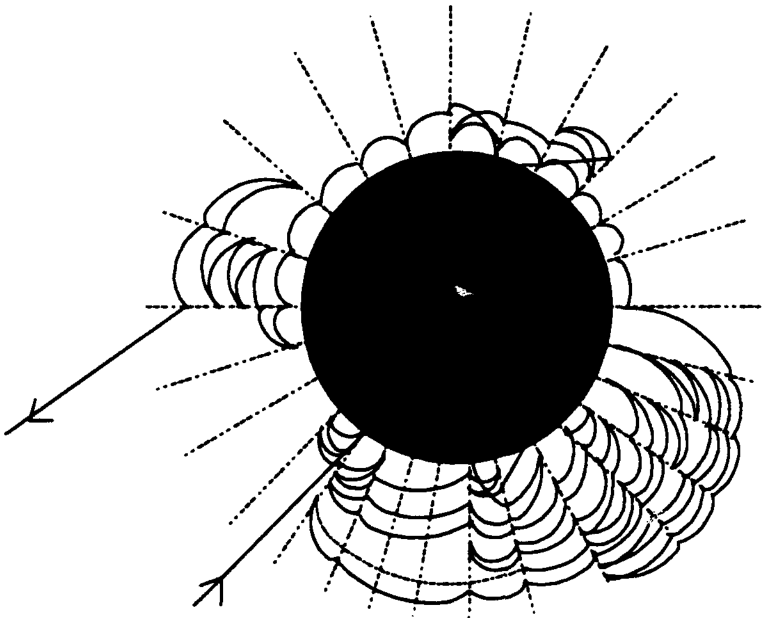
HAPTIC

[bcbcbabaxwxwqxwvwxabaxwvutuvwxwvutuvutstu vw baxwvutststsrsrstuvutsrstuvutsrqponmlklmnmn lkjihgfefgfgfghgf ** edcbabcdefghijklmnoponopqr srstrstuvwvuvutstuvutuvwxvwxabcb]

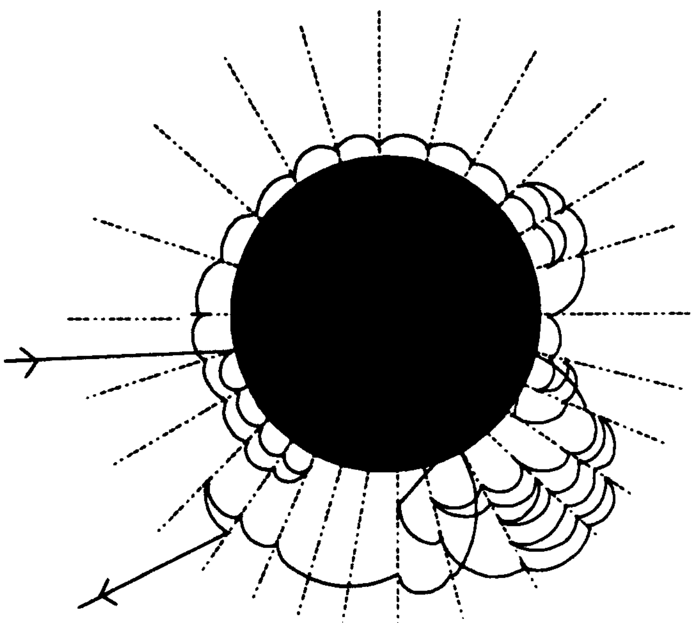
Sr = 96.20 %

| K | HAPTIC |
|---|---|

## Recognition Phase

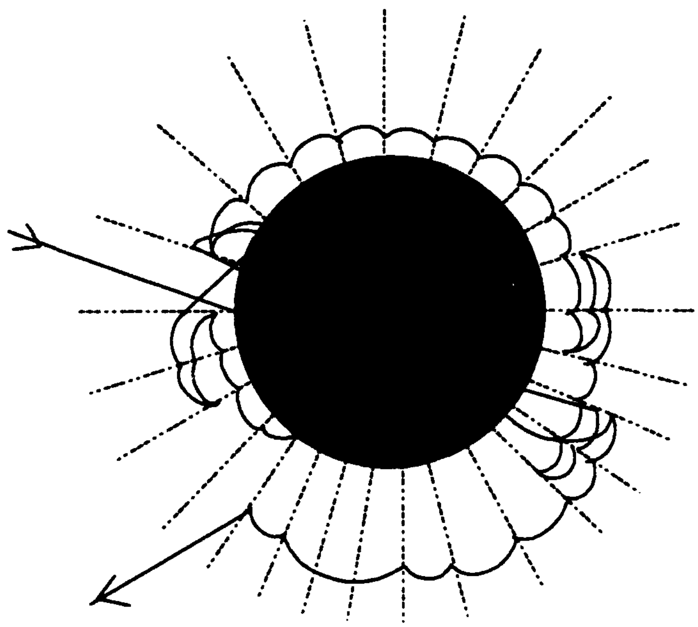


## Post Recognition Phase

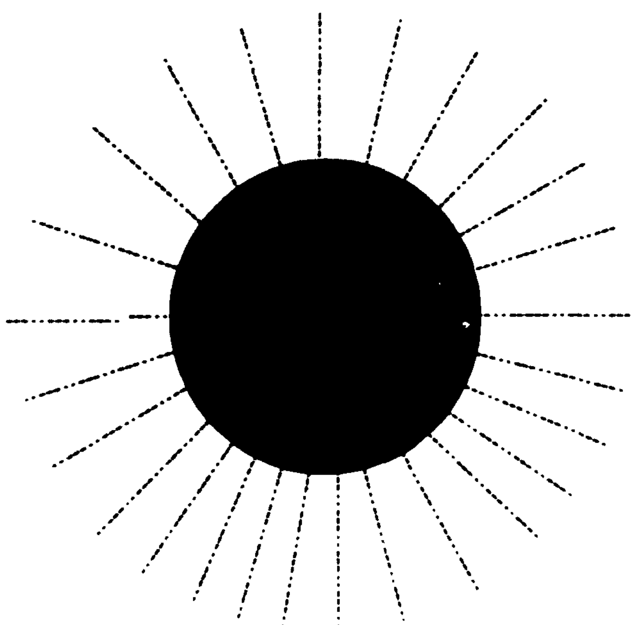


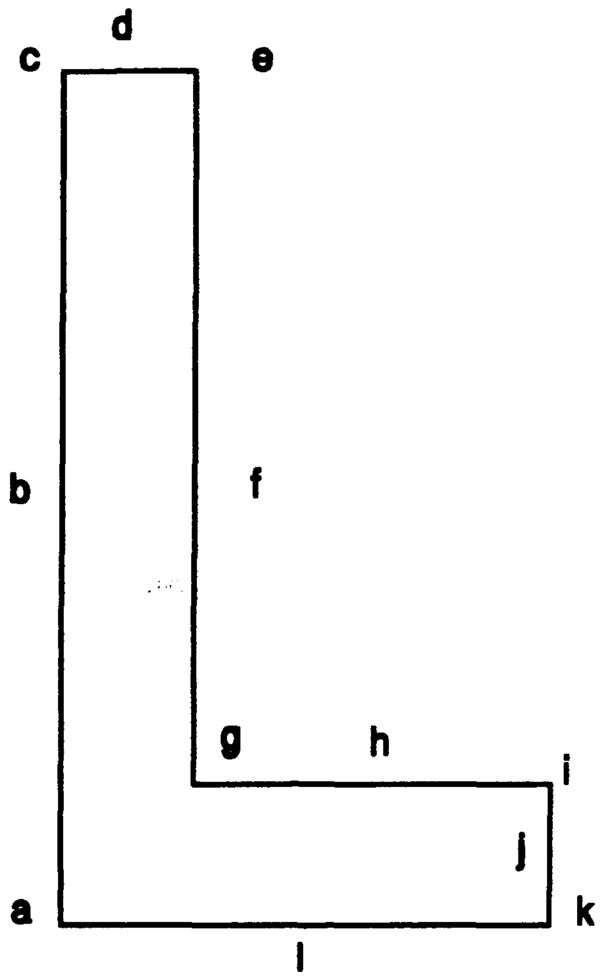
| K | S.F.V.S. |
| --- | --- |

**Recognition Phase**



**Post Recognition Phase**






S.F.V.S.

[balkjkjihgfedcb ** fbfb]

Sr = 70.59 %

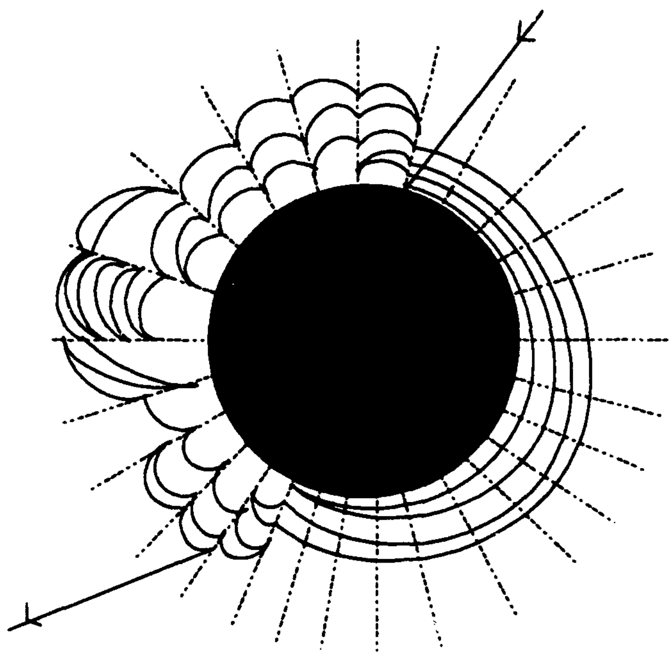
HAPTIC

[lalklabalkjihghijklkjihgfgfgfghgfefedcbabcdcb ** alkjihgfedcbl]

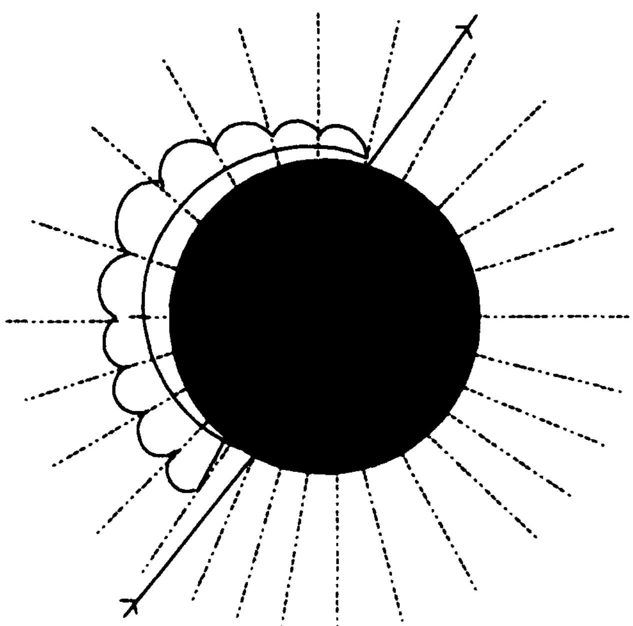
Sr = 98.25 %

| L | HAPTIC |
|---|---|

**Recognition Phase**



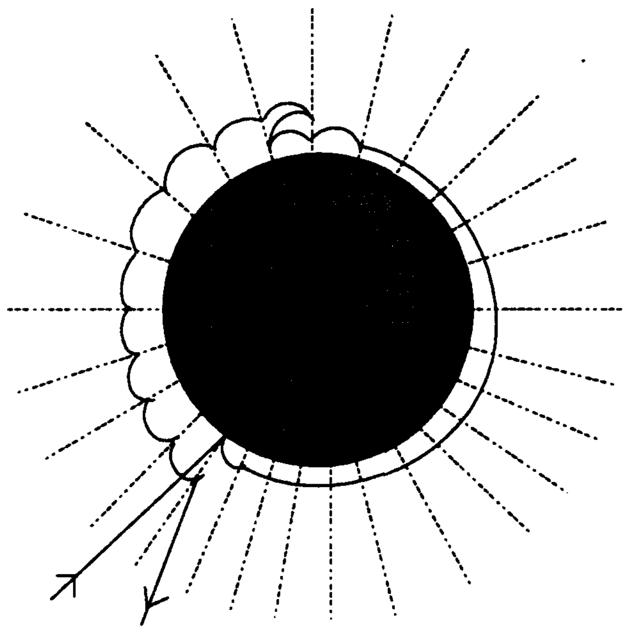
**Post Recognition Phase**



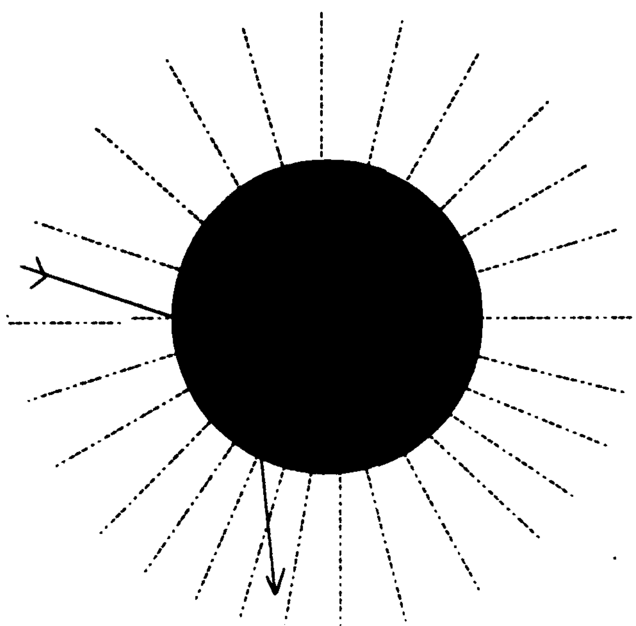
L

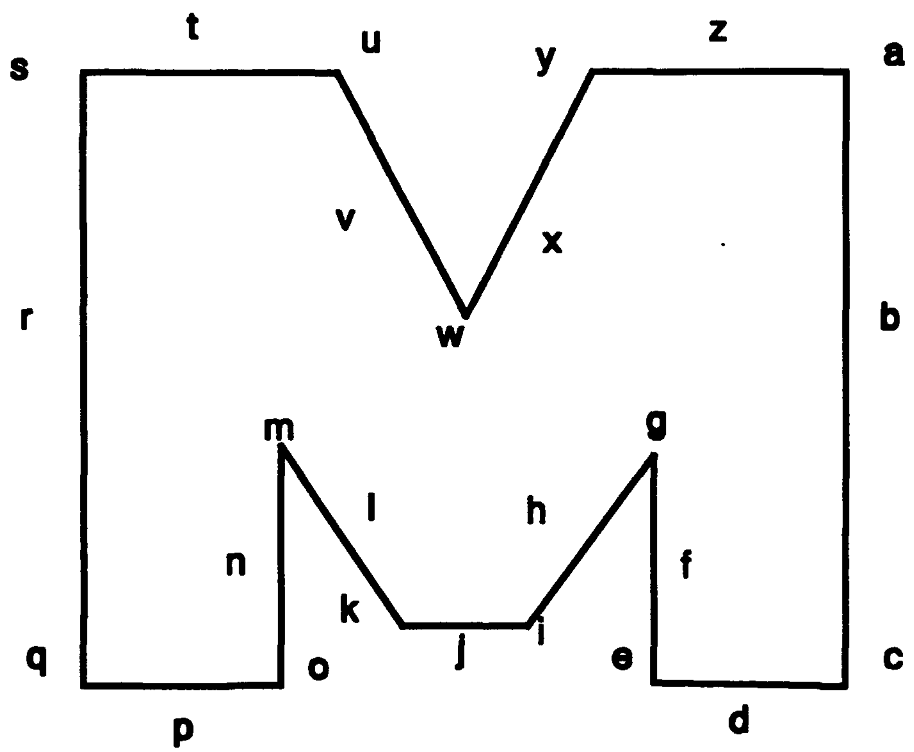
## S.F.V.S.

### Recognition Phase



### Post Recognition Phase






**S.F.V.S**

[l m l m r m n o p r s v w x z a b c d f d c b c d f g h w m w h g f b f g h i l k l m r ]

S r = 62.79 %

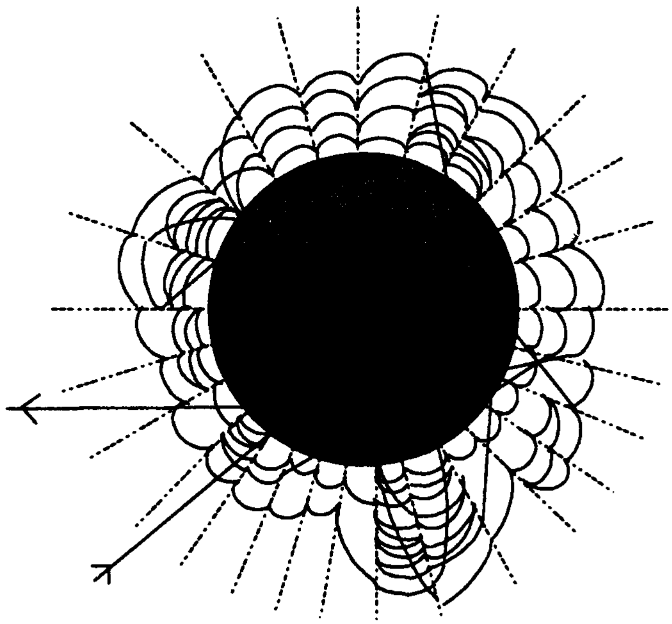
**HAPTIC**

[b c b c d e f e d e f g h g f g h g h i j k l m l m l m n m n o p q r s t u v w x w v w x y z a b c b a r l x w v w x w x w v w x w v r b r n l j h g f h i j k l m l m n o p q r v w x y z a b c d e f g h i j k l m n o p q r b x w v u t s t u t s r l h i j k l r b]

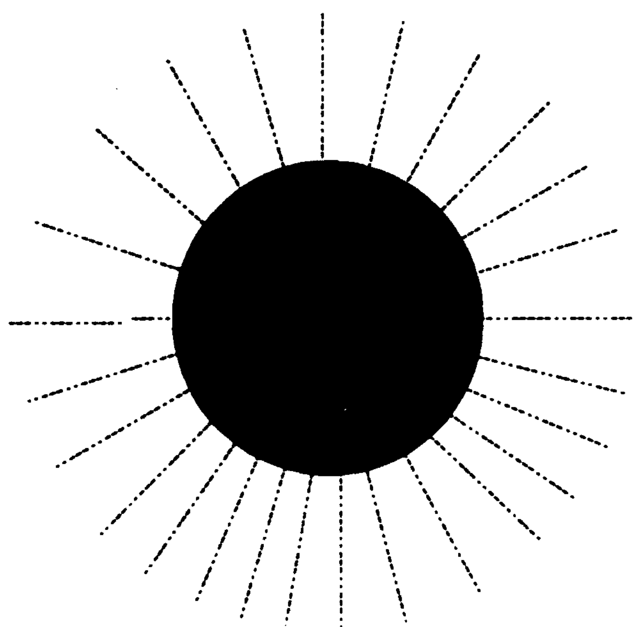
S r = 86.26 %

M HAPTIC

Recognition Phase



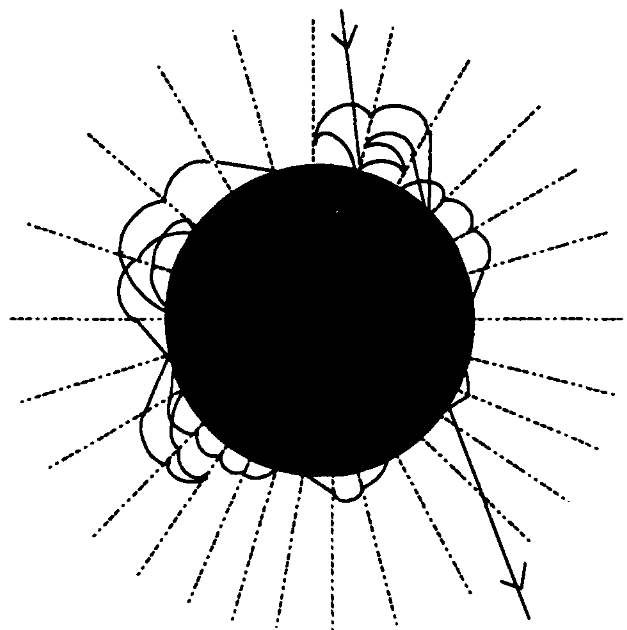
Post Recognition Phase



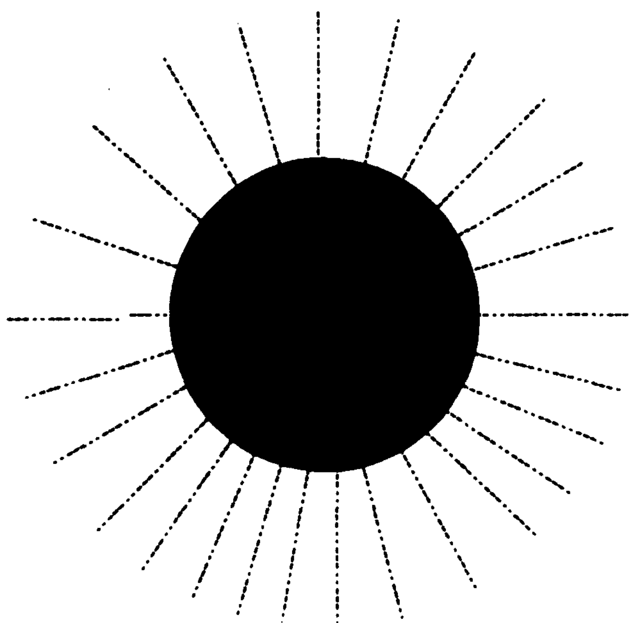
M

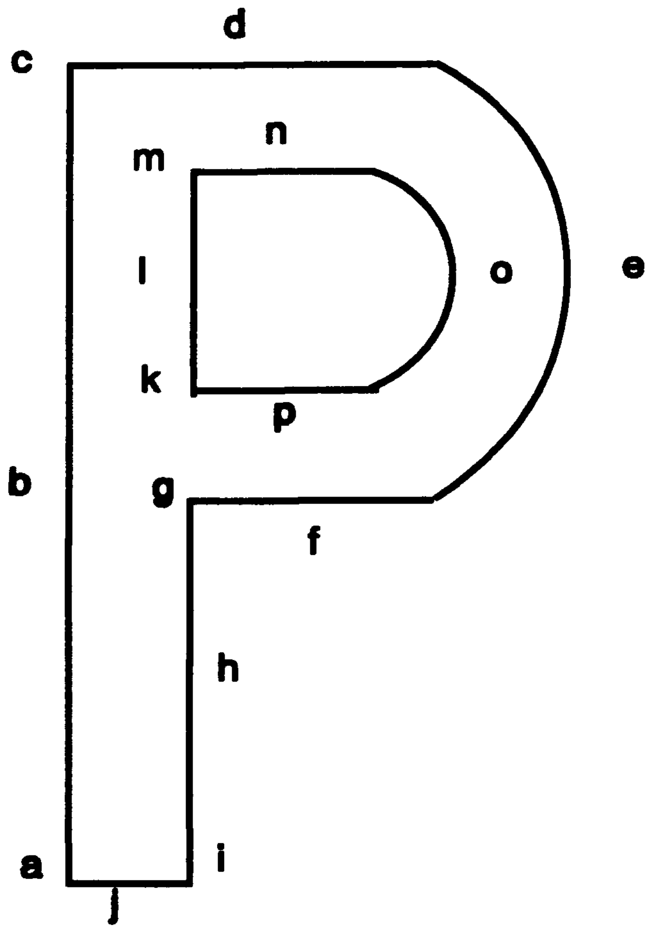
**S.F.V.S.**

**Recognition Phase**



**Post Recognition Phase**






**S.F.V.S**

[bcdefhij ** lo blmnml]

S r = 66.67 %

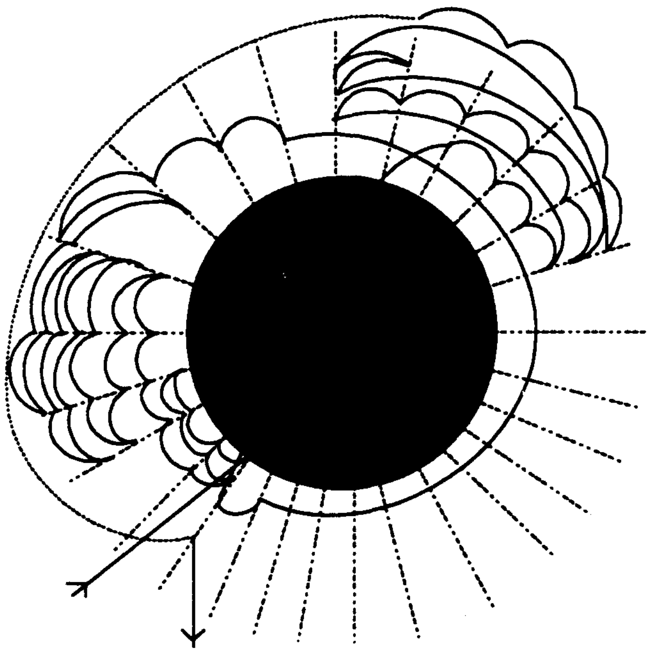
**HAPTIC**

[bcdedcbcdefgfedefgfedefgfefghghijablm nopklmnopklmnopklkponml b]

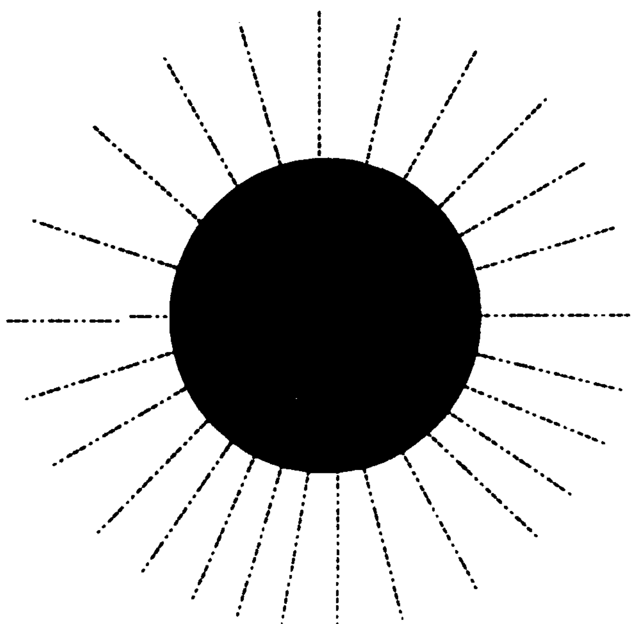
S r = 96.67 %

| P | HAPTIC |
| --- | --- |

**Recognition Phase**

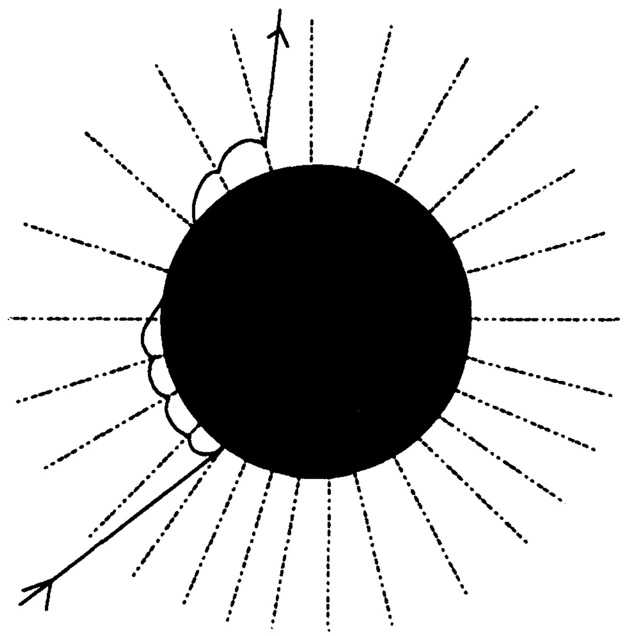


**Post Recognition Phase**

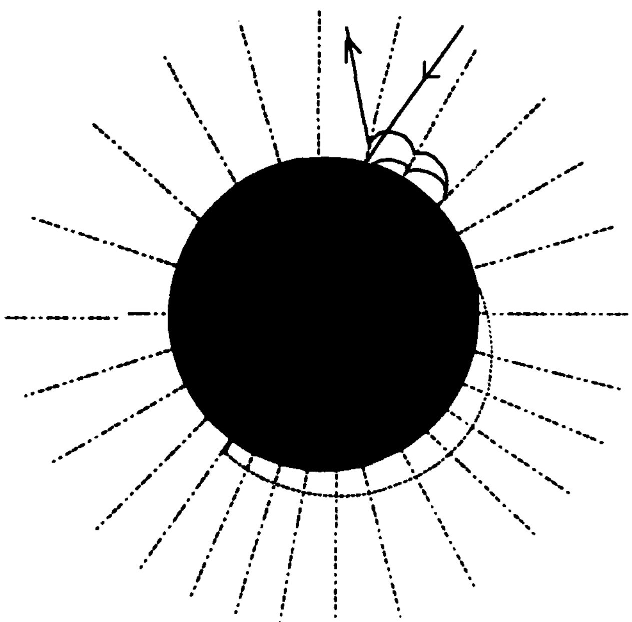


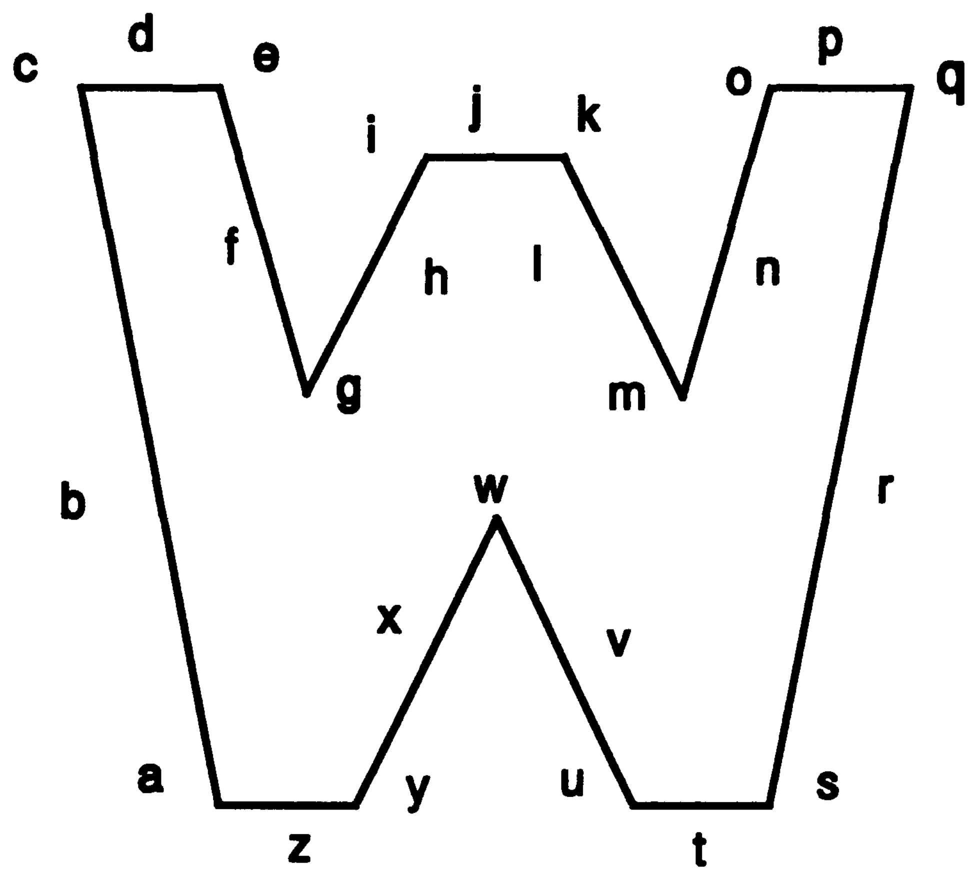
| P | S.F.V.S. |
|---|---|

### Recognition Phase



### Post Recognition Phase






S.F.V.S.

[hijklmn rvutsrq nlmlmvwvwxvxyzabcd fghij kl]

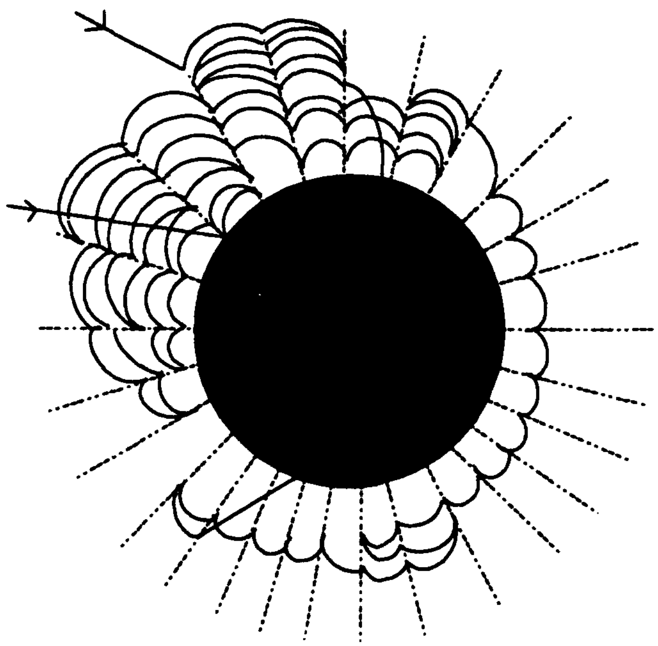
Sr = 78.95 %

HAPTIC

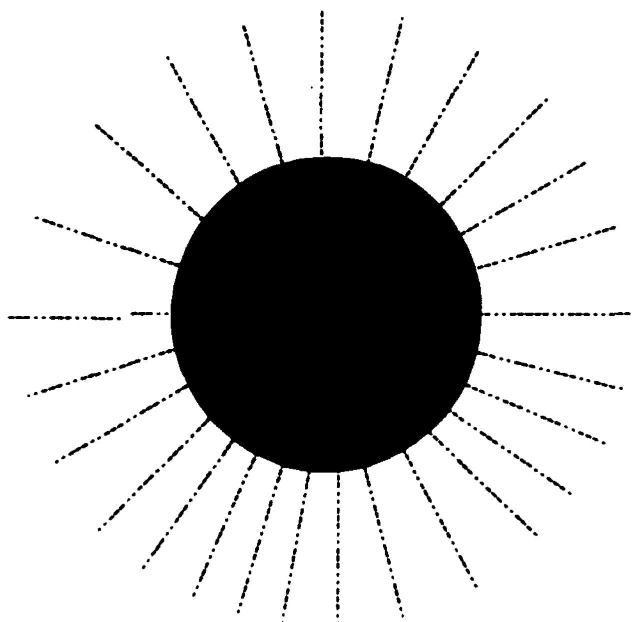
[hihgfefghgfghihgfedefghijklmlkjihghijklmlmn opqrstuvwxwvwxyzabcbrbrlkjijkjijkji]

Sr = 94.81 %

| W | HAPTIC |
|---|---|
| | Recognition Phase |

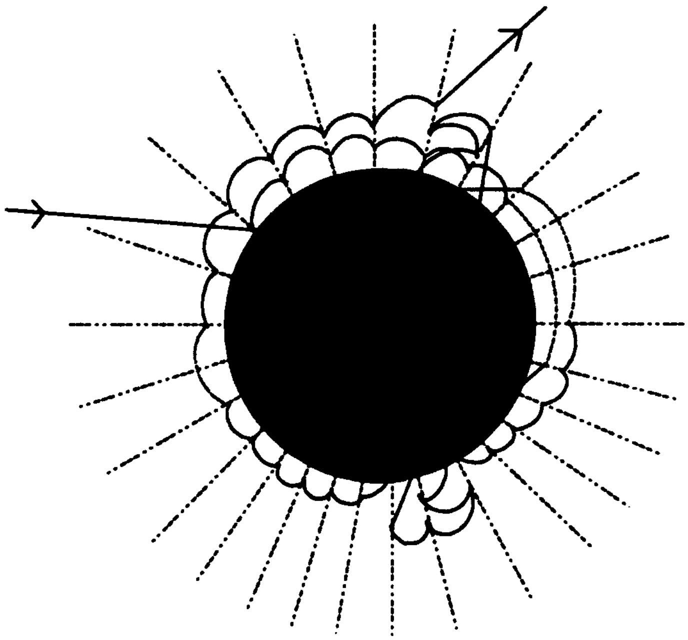


Post Recognition Phase

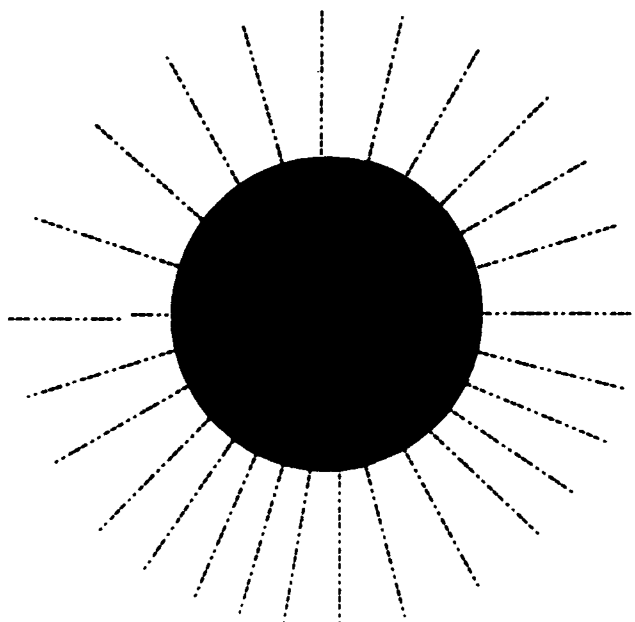


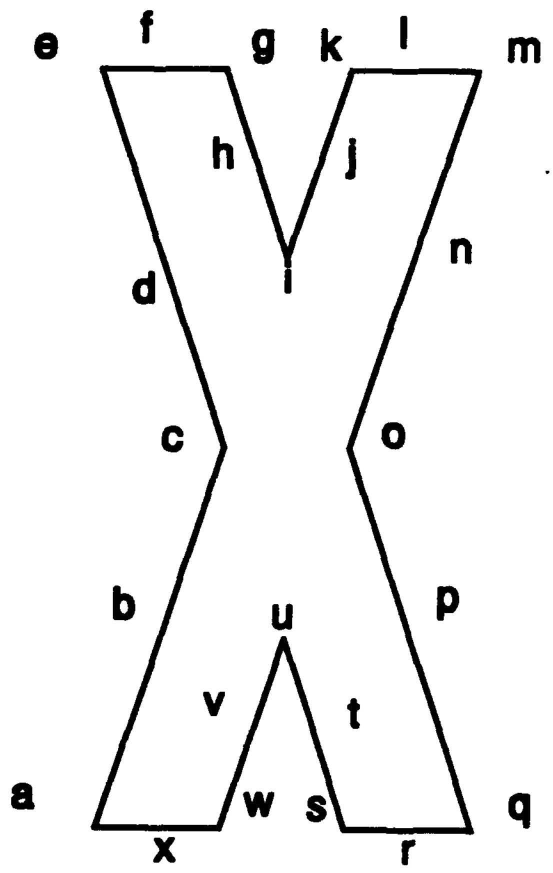
**W** **S.F.V.S.**

**Recognition Phase**



**Post Recognition Phase**






**S.F.V.S.**

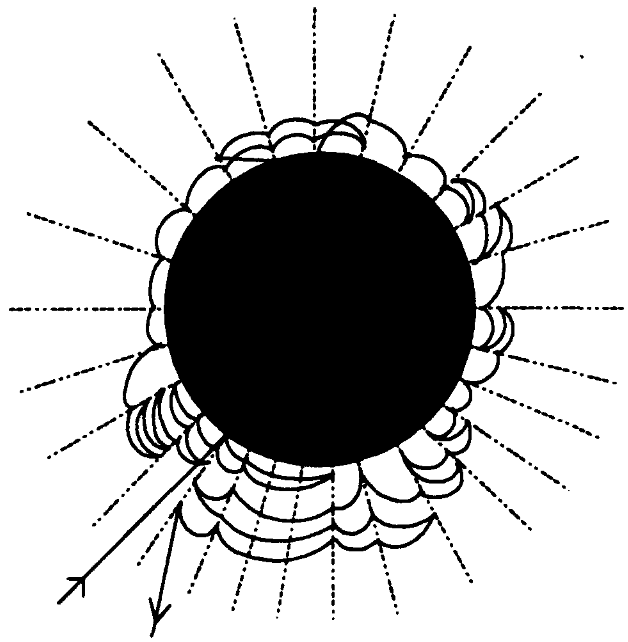
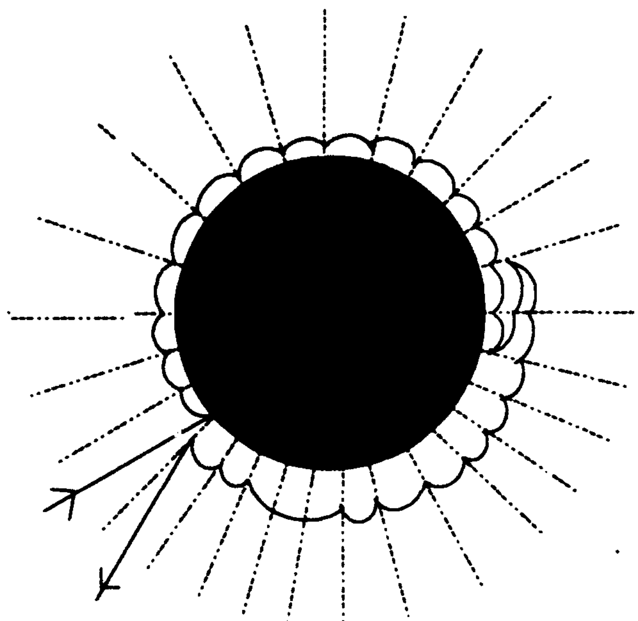
[fedcb dcbaxw axwvtsrqrq pn mlkjihgfe]

Sr = 87.10 %

**HAPTIC**

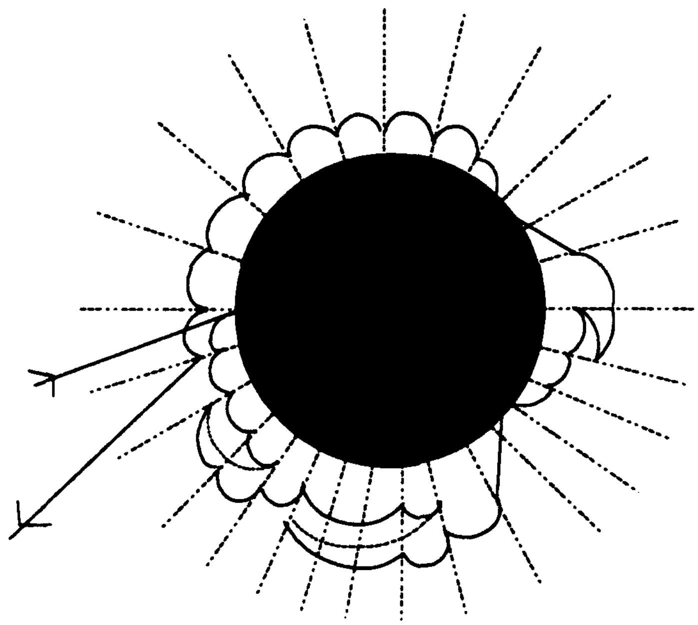
[baxabcdcbcdcbcdefghijklkjiklmnonopopqrqrstutu vuvwxabaxwvwxab**cdefghijklmnopqrqpqrstuvwx abc]

Sr = 98.86 %

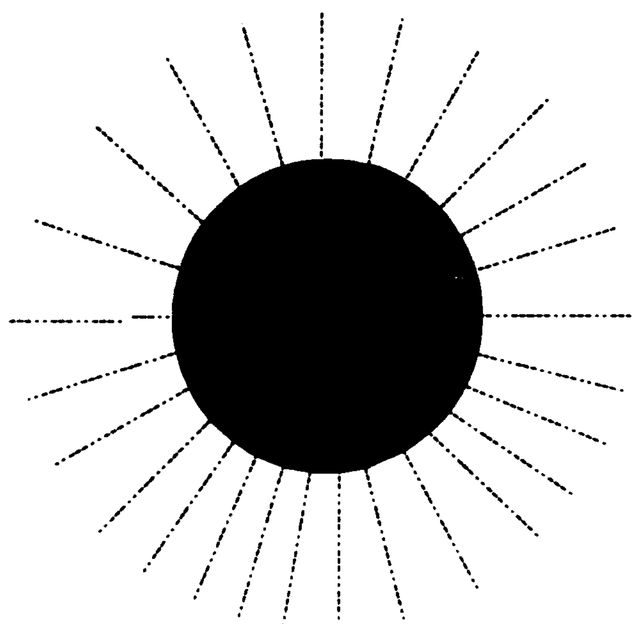
| X | HAPTIC |
| --- | --- |
| | Recognition Phase |
| |  |
| | Post Recognition Phase |
| |  |

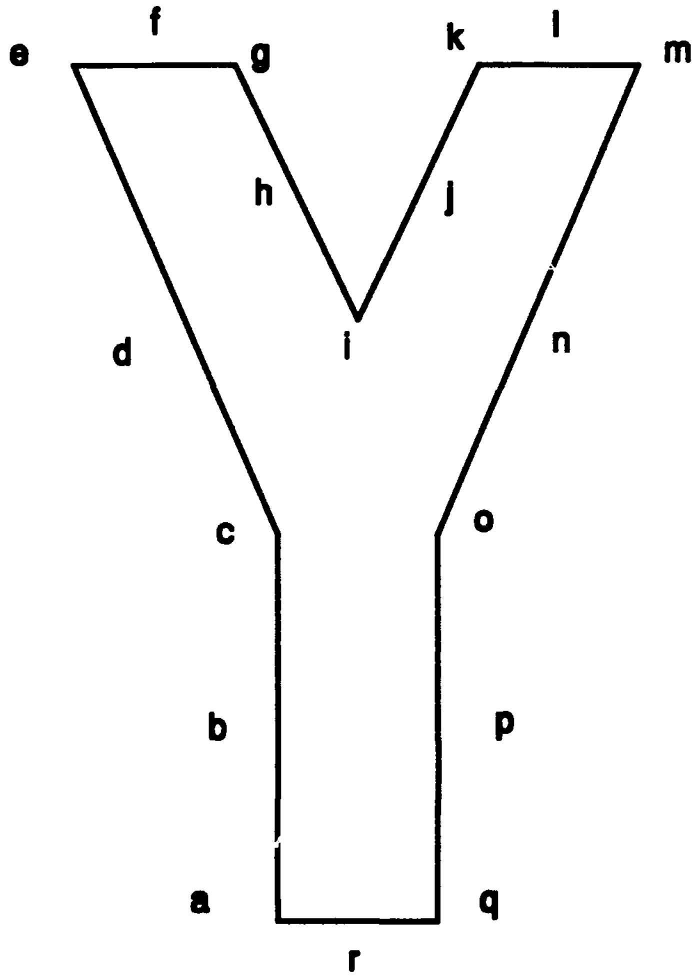
**X** **S.F.V.S.**

**Recognition Phase**



**Post Recognition Phase**






**S.F.V.S.**

[ndonpqradfghijn qrabcdi]

Sr = 61.90 %

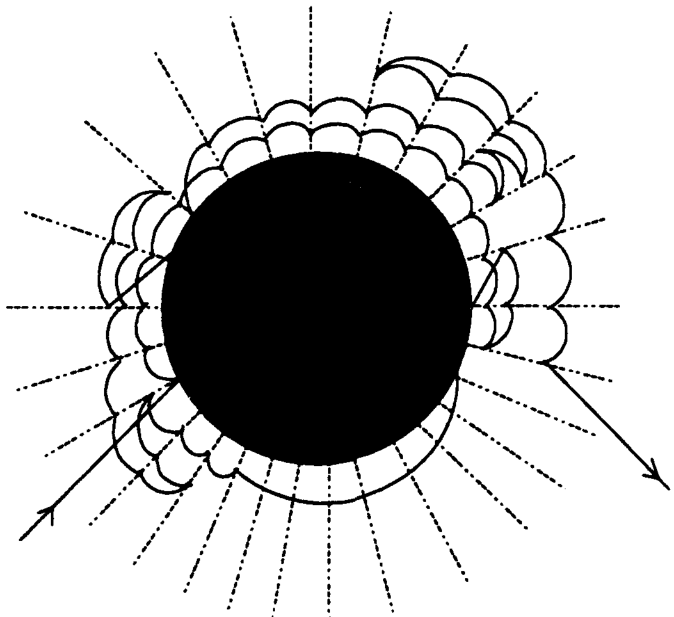
**HAPTIC**

[defghijklmnopqrqprabcdcbcdefghgfhijklmnono nmlmnopqr]

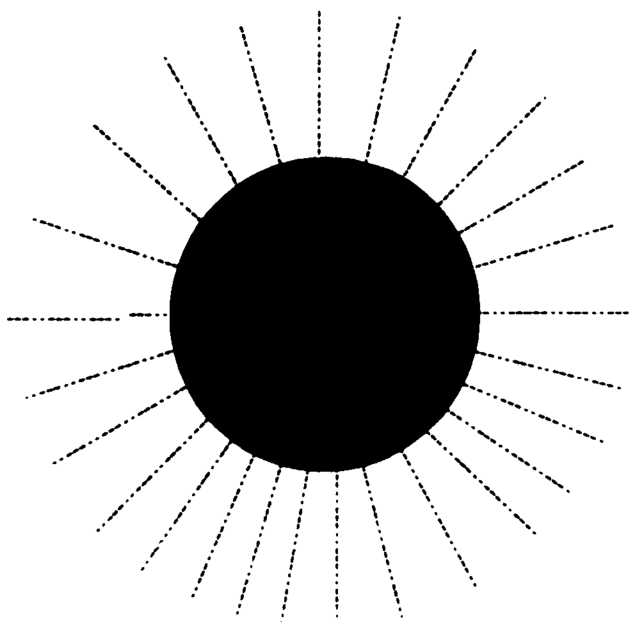
Sr = 98.00 %

| Y | HAPTIC |
| --- | --- |

**Recognition Phase**

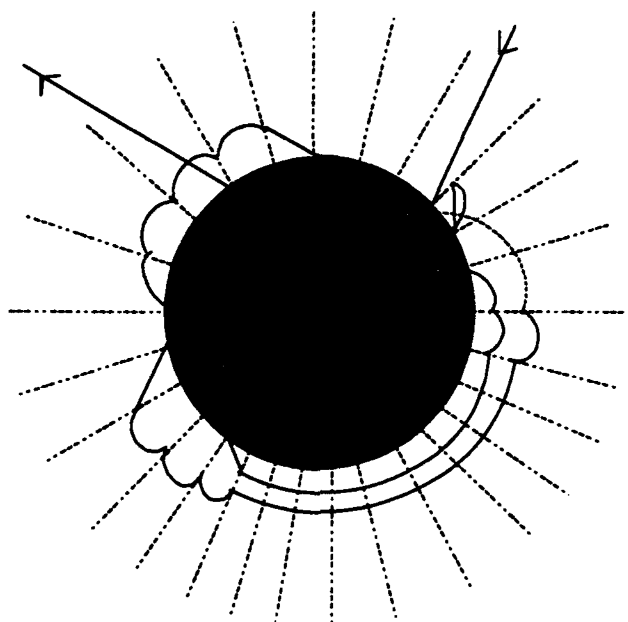


**Post Recognition Phase**

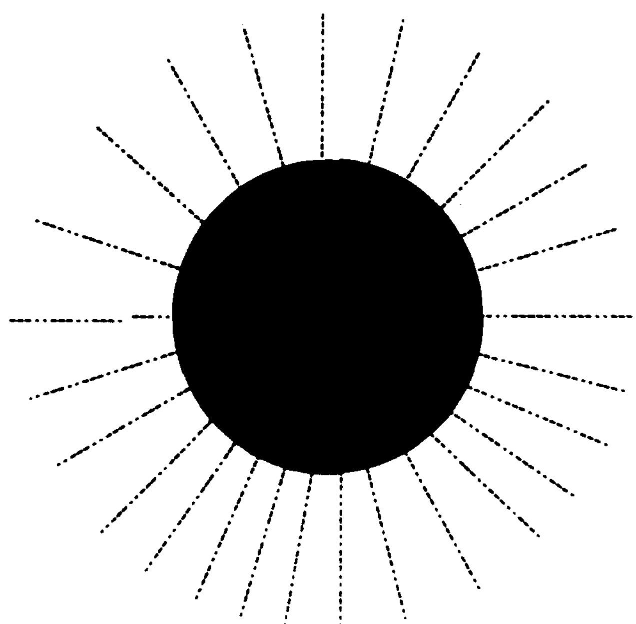


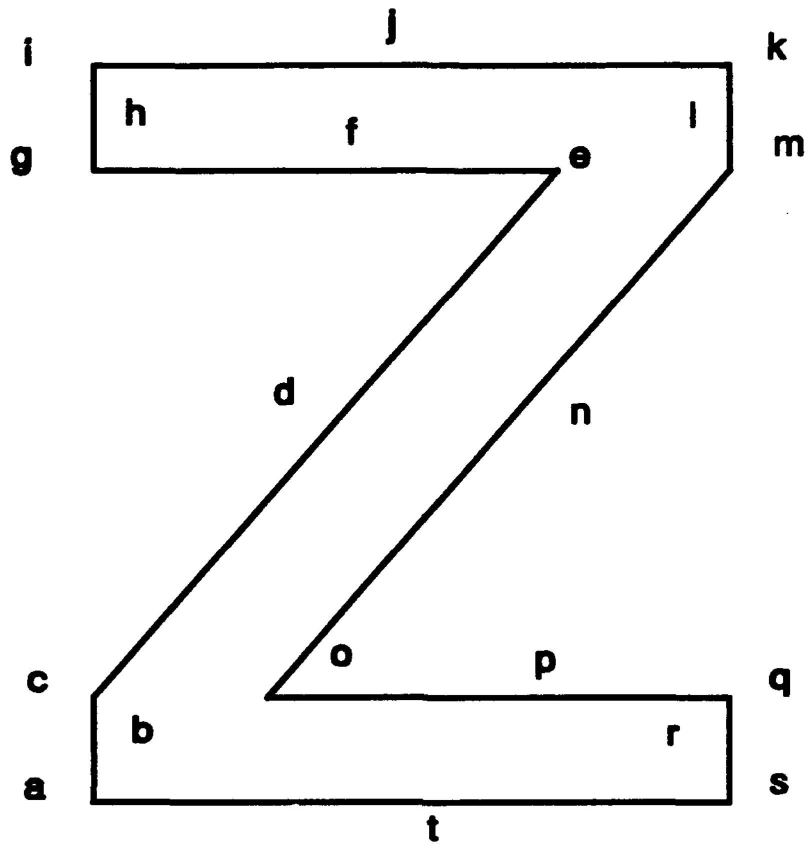
| Y | S.F.V.S. |
|---|---|

## Recognition Phase



## Post Recognition Phase






### S.F.V.S.

[dehj edcbatsrqpnml ihfed]

Sr = 71.43 %

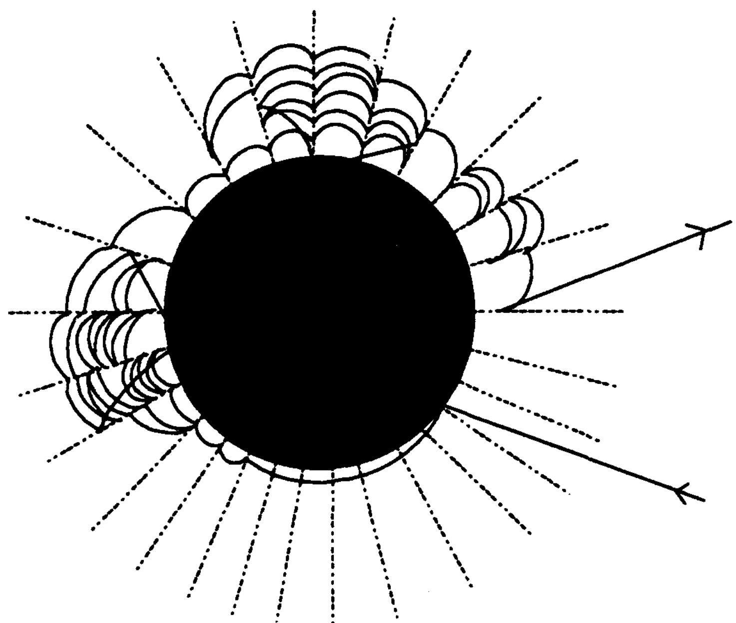
### HAPTIC

[tabcdededefefgfefedcdedefgedefghijklmlkj
klmkjklkjijklmnonopopq ** tabcdedcbatsrqp
onoponmlmlkjijklmnopqrstabcdefghijklmno]

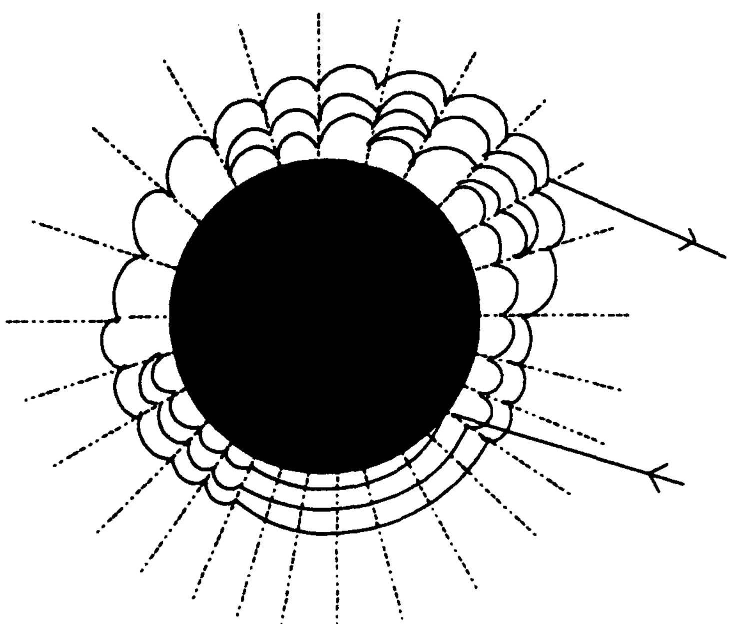
Sr = 99.14%

| Z | HAPTIC |
|---|---|

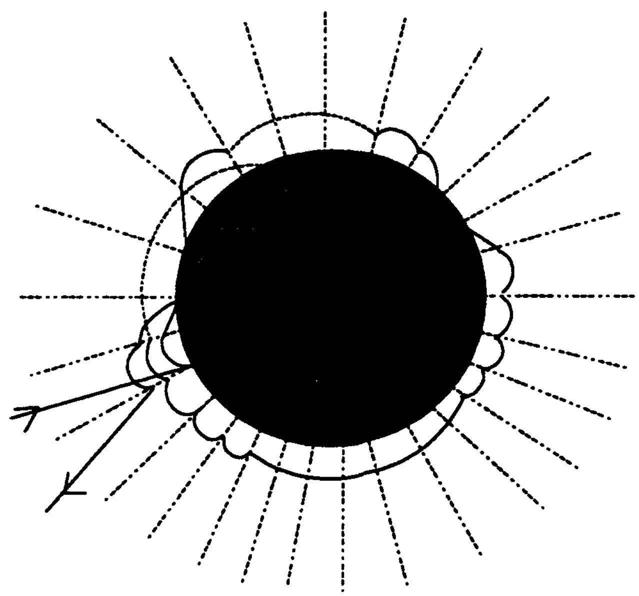
**Recognition Phase**



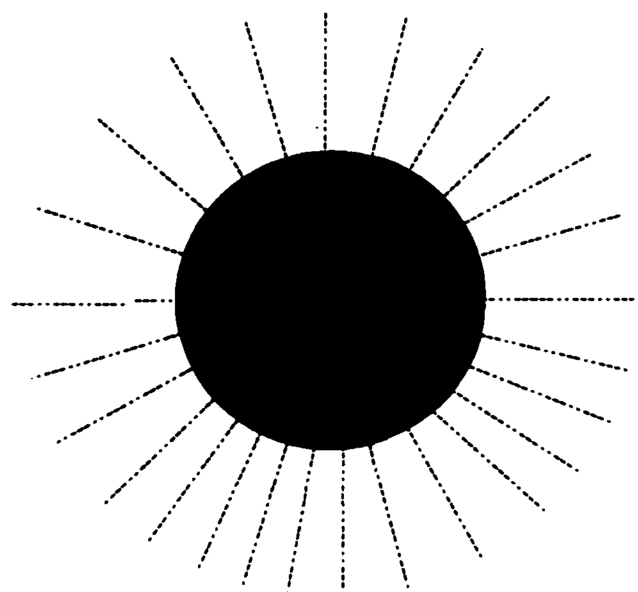
**Post Recognition Phase**



| Z | S.F.V.S. |
|---|---|
| | **Recognition Phase** |



**Post Recognition Phase**



## APPENDIX B: SOFTWARE LISTING

```
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
' THIS PROGRAM SIMULATES THE FOVEAL VISION SEARCH FOR  '
' OBJECT IDENTIFICATION.                               '
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
1000 COMMON JOY!()
1010 CLS
1020 OPTION BASE 1
1030 DIM ALPHA$(26)
1040 DIM JOY!(10000)
1050 OPEN "JOY.DAT" FOR OUTPUT AS #1
1060 COUNT = 3
1070 SEED = VAL(RIGHT$(TIME$, 2))
1080 PRINT "PRESS ENTER TO START THE PROGRAM SESSION"
1090 INPUT "", R$
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
' CALIBRATION VALUES FOR VIEW WINDOW AND JOYSTICK      '
' COORDINATES,CHANGE TO GRAPHIC SCREEN MODE.           '
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
1100 DX = 6: DY = 3
1110 XMAX = 260: YMAX = 242
1120 SCREEN 2
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
' SUBROUTINE CONTAINING SET OF GRAPHIC LETTERS,        '
' STRING VARIABLES.                                    '
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
1130 GOSUB 1800
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
' RANDOMIZES SELECTION OF LETTER AND ANGLE OF ROTATION. '
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
1140 RANDOMIZE (SEED)
1150 ANG = INT(RND(1) * (361))
1160 ROT$ = STR$(ANG)
1170 ID = INT(RND(2) * (27))
1180 LETTER$ = ALPHA$(ID)
1190 JOY(1) = ID
1200 JOY(2) = ANG
1210 ARG$ = "ta" + ROT$ + LETTER$
```

```
1220 WRITE #1, JOY(1), JOY(2)
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
' SCALING OF VIEW WINDOW AND JOYSTICK COORDINATES     '
' FOR GRAPHIC SCREEN.                                 '
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
1230 XSCALE = 640 / XMAX: YSCALE = 200 / YMAX
1240 X = STICK(0): Y = STICK(1)
1250 X = INT(X * XSCALE): Y = INT(Y * YSCALE)
1260 X1L = X1: Y1L = Y1: X2L = X2: Y2L = Y2
1270 X1 = X - DX: Y1 = Y - DY: X2 = X + DX: Y2 = Y + DY
1280 IF (X2 > 639) THEN X2 = 639
1290 IF (X1 < 1) THEN X1 = 1
1300 IF (Y2 > 199) THEN Y2 = 199
1310 IF (Y1 < 1) THEN Y1 = 1
1320 LINE (X1L, Y1L)-(X2L, Y2L), 0, BF
1330 VIEW SCREEN (X1, Y1)-(X2, Y2)
1340 WINDOW SCREEN (X1, Y1)-(X2, Y2)
1350 LINE (X1, Y1)-(X2, Y2), 0, B
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
' GRAPHIC LETTER DISPLAY AND DATA COLLECTION.         '
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
1360 DRAW "bm 320,100"
1370 DRAW ARG$
1380 JOY(COUNT) = STICK(0)
1390 JOY(COUNT + 1) = STICK(1)
1400 WRITE #1, JOY(COUNT), JOY(COUNT + 1)
1410 A$ = INKEY$: IF A$ <> "" THEN 1440
1420 COUNT = COUNT + 2
1430 GOTO 1240
1440 CLOSE 1
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
' TEXT MODE SCREEN OR REPRODUCTION OF SEARCH MODEL.   '
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
1450 SCREEN 0
1460 PRINT "DO YOU WANT TO RECREATE THE WINDOW PATH?(y/n)"
1470 INPUT "", R$
1480 IF R$ = "n" THEN GOTO 1780
1490 SCREEN 2
1500 OPEN "JOY.DAT" FOR INPUT AS #1
1510 COUNT = 3
1520 INPUT #1, JOY(1), JOY(2)
1530 ID = JOY(1)
1540 ANG = JOY(2)
```

```
1550 LETTER$ = ALPHA$(ID)
1560 ROT$ = STR$(ANG)
1570 ARG$ = "ta" + ROT$ + LETTER$
1580 DO UNTIL EOF(1)
1590 INPUT #1, JOY(COUNT), JOY(COUNT + 1)
1600 X = JOY(COUNT)
1610 Y = JOY(COUNT + 1)
1620 X = INT(X * XSCALE)
1630 Y = INT(Y * YSCALE)
1640 X1 = X - DX: Y1 = Y - DY: X2 = X + DX: Y2 = Y + DY
1650 LINE (X1, Y1)-(X2, Y2), , B
1660 FOR J = 1 TO 10
1670 DRAW "bm 320,100"
1680 DRAW ARG$
1690 NEXT J
1700 LINE (X1, Y1)-(X2, Y2), 0, B
1710 A$ = INKEY$: IF A$ <> "" THEN 1740
1720 COUNT = COUNT + 2
1730 LOOP
1740 CLOSE 1
1750 SCREEN 0
1760 PRINT "THE PROGRAM SESSION IS FINISHED, PRESS ENTER TO EXIT"
1770 INPUT "", R$
1780 STOP
1790 END
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
' SUBROUTINE OF STRING VARIABLES.
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''

1800 ALPHA$(1) = "c3 s10 bm +10,+10 m+8,18 r20 m-32,-60 l20 m-32,60 r20
m+8,-18 r28 bm-4,-8 l20 m+10,-18 m+10,+18 "
1810 ALPHA$(2) = _
"c3 s10 bm +20,-30 l40 d60 r40 bm+0,-8 l24 u18 r20 bm +0,-10 l20 u16 r20 m+5,1
m+5,2 m+3,2 d7 m-3,2 m-2,1 m-3,1 m-3,1 m-2,0 bm-0,10 m+5,1 m+5,2 m+3,2 d9
m-3,2 m-2,1 m-2,1 m-3,1 bm-0,8 m+9,-1 m+3,-1 m+3,-1 m+3,-1 m+4,-2 m+4,-3
m+2,-3 m+1,-3 u6 m-1,-3 m-2,-3 m-4,-3 m-4,-2 m-3,-1 m+2,-1 m+2,-1 m+2,-1
m+2,-1 m+3,-2 m+2,-2 m+1,-3 m+1,-3 u3 m-1,-3 m-2,-3 m-4,-3 m-4,-2 m-3,-1 m
-3,-1 m-3,-1 m-4,-1 m-2,-0 m-2,0" _

1820 ALPHA$(3) = _
"c3 s10 bm+16,20 bm+0,-44 m-1,-2 m-3,-4 m-4,-3 m-3,-1 m-3,-1 l43 m-2,+0
m-3,+1 m-3,+1 m-4,+3 m-3,+3 m-1,+3 d44 m+2,+3 m+3,+3 m+4,+3 m+3,+1
m+3,+1 m+2,0 r43 m+3,-1 m+3,-1 m+4,-3 m+3,-4 m+1,-2 l20 m-2,+2 m-2,+1
```

```
m-2,+1 l19 m-2,-1 m-2,-1 m-3,-2 u43 m+3,-2 m+2,-1 m+2,-1 r19 m+2,+1 m+2,+1
m+2,+2 r19" _

1830 ALPHA$(4) = _
"c3 s10 bm +12,28 l28 u60 r28 bm+0,8 l12 d44 r12 S5 M+20,-2 M+20,-2 M+10,-4
M+10,-6 M+6,-8 M+4,-10 U28 M-4,-10 M-6,-8 M-10,-6 M-10,-4 M -20,-2 m-20,-2
bm +0,-16 m+20,+2 m+20,+2 m+18,+4 m+12,4 m+10,4 m +8,4 m+6,4 m+4,4
m+2,4 m+2,4 d39 m-2,4 m-2,4 m-2,4 m-2,4 m-4,4 m-4,4 m-6,4 m-8,4 m-10,4
m-12,4 m-18,4 m-20,2 m-20,2" _

1840 ALPHA$(5) = "c3 s10 u8 l24 u16 r40 u8 l60 d60 r60 u8 l40 u20 r24"
1850 ALPHA$(6) = "c3 s10 u8 l24 u16 r40 u8 l60 d60 r20 u28 r24 "
1860 ALPHA$(7) = _
"c3 s10 bm+16,20 bm+0,-44 m-1,-2 m-3,-4 m-4,-3 m-3,-1 m-3,-1 l43 m-2,+0
m-3,+1 m-3,+1 m-4,+3 m-3,+3 m-1,+3 d44 m+2,+3 m+3,+3 m+4,+3 m+3,+1 m+2,0
r44 m+3,-1 m+3,-1 m+4,-3 m+3,-4 m+1,-2 u16 l30 d8 r12 d8 m-2,+2 m-2,+1
m-2,+1 l19 m-2,-1 m-2,-1 m-3,-2 u43 m+3,-2 m+2,-1 m+2,-1 r19 m+2,+1 m+2,+1
m+2,+3 r19" _

1870 ALPHA$(8) = "c3 s10 d25 r20 u60 l20 d25 l32 u25 l20 d60 r20 u25 r32"
1880 ALPHA$(9) = "c3 s10 d30 l20 u60 r20 d30  "
1890 ALPHA$(10) = _
"c3 s10 bm +0,14 u44 r20 d44 s5 m-0,1 m-1,2 m-1,3 m-1,4 m-2,3 m-3,3 m-4,3
m-5,3 m-6,3 m-7,3 m-8,3 m-9,3 m-12,3 m-15,0 m-12,-2 m-9,-2 m-8,-2 m-8,-3
m-8,-3 s5 m-8,-6 m-6,-12 m-0,-10 r35 m+0,+10 m+6,+8  m+8,+2 m+8,+2 s5
m+12,0 m+8,-2 m+4,-2 m+4,-2 m+2,-2 m+3,-8" _

1900 ALPHA$(11) = "c3 s10 bm+20,32 r20 m-22,-40 m+22,-20 l20 m-28,24 u24
l20 d60 r20 u18 m+10,-8   m+18,26  "
1910 ALPHA$(12) = "c3 s10 d20 r40 d8 l60 u60 r20 d40"
1920 ALPHA$(13) = "c3 s10 m+24,-34 r20 d60 l20 u34  m-20,34 l8 m-20,-34 d34
l20 u60 r20 m+24,34"
1930 ALPHA$(14) = "c3 s10  U36 R20 D60 L20 M-36,-36 D37 l20 u60 r20
m+36,36"
1940 ALPHA$(15) = _
"c3 s10 bm +16,20 u44 bm -20,0 d43 bm-32,0 u43bm-20,0  d44 m+2,+3 m+3,+3
m+4,+3 m+3,+1 m+3,+1 m+2,0 r43 m+3,-1 m+3,-1 m+4,-3 m+3,-4 m+1,-2
bm-21,-1 m-2,+2 m-2,+1 m-2,+1 l19 m-2,-1 m-2,-1 m-3,-2 bm-0,-43 m+3,-2 m+2,-1
m+2,-1 r19 m +2,+1 m+2,+1 m+2,+2 bm +20,0 m-1,-2 m-3,-4 m-4,-3 m-3,-1 m-3,-1
l43 m-2,+0 m-3,+1 m-3,+1 m-4,+3 m-3,+3 m-1,+3 " _

1950 ALPHA$(16) = _
```

```
"c3 s10 bm+20,0 l20 d26 l20 u60 r36 bm+0,8 l18 d16 r18 S5 M+6,-1 M+6,-1
M+4,-1 M+2,-2 M+2,0 M+2,-3 S5  M+2,0 M+2,-3  m+1,-4 m+1,-3 m-1,-4  m-1,-4
m-2,-3 m-2,0 m-2,-3 m-2,0 m-2,-2 m-4,-1 m-6,-1 m-6,-1  bm +8,52 s10 m+5,-1
m+5,-1  m+4,-1  m+2,-2  m+2,0  m+2,-3  m+2,0  m+2,-3   m+1,-3  m+1,-4  m-1,-4
m-1,-4 m-2,-3 m-2,0 m-2,-3 m-2,0 m-2,-2 m-5,-1 m-7,-1 m-7,0" _

1960 ALPHA$(17) = _
"c3 s10 bm +16,20 u44 bm -20,0 d43 bm-32,0 u43bm-20,0  d44 m+2,+3 m+3,+3
m+4,+3  m+3,+1  m+3,+1  m+2,0  r41   m  +10,6  m+9,-4   m-8,-5  m+3,-4  m+1,-2
m+1,-2  bm  -21,-1  m-2,+2  m-2,+1  m-2,+1  l19  m-2,-1  m-2,-1  m-3,-2  bm-0,-43
m+3,-2 m+2,-1 m+2,-1 r19 m+2,+1 m+2,+1 m+2,+2 bm+20,0 m-1,-2 m-3,-4 m-4,-3
m-3,-1  m-3,-1  l43  m-2,+0  m-3,+1  m-3,+1  m-4,+3  m-3,+3  m-1,+3" _

1970 ALPHA$(18) = "c3 s10  l17 u14 r17 bm+0,-8 l36 d60 r20 u30 r16  m+16,30
r20 m-16,-31 m+5,-3 m+4,-3 m+3,-3 m+2,-3 u7 m-2,-3 m-3,-3 m-4,-3 m-5,-3  l20
c3 s5 bm -0,+16 m+5,+2 m+4,+2 m+3,+2 m+3,+2 m+3,+2 d12  m-3,+2 m-3,+2
m-3,+2 m-4,+2 m-5,+2"
1980 ALPHA$(19) = "c3 s10 bm+28,-24 u8 l60 d8 r40 m-44,44 d8 r62 u8 l40
m+42,-44"
1990 ALPHA$(20) = "c3 s10  u26 r20 u8 l60 d8 r20 d52 r20 u26"
2000 ALPHA$(21) = "c3 s10 bm +16,20 u44 l20 d43 bm-32,0 u43 l20 d44 m+2,+3
m+3,+3 m+4,+3 m+3,+1 m+3,+1 m+2,0 r43 m+3,-1 m+3,-1 m+4,-3 m+3,-4 m+1,-2
bm-21,-1 m-2,+2 m-2,+1 m-2,+1 l19 m-2,-1 m-2,-1 m-3,-2"
2010 ALPHA$(22) = "c3 s10 m+22,-38 r20 m-32,60 l20 m-32,-60 r20 m+22,38"
2020 ALPHA$(23) = "c3 s10 m+14,32 r20 m+20,-60 l20 m-12,32 m-12,-32 l20
m-12,32 m-12,-32 l20 m+20,60 r20 m+14,-32"
2030 ALPHA$(24) = "c3 s10 m+24,-28 l20 m-16,18 m-16,-18 l20 m+24,28 m-24,28
r20 m+16,-18 m+16,18 r20 m-24,-28"
2040 ALPHA$(25) = "c3 s10 m+28,-32 l20 m-20,18 m-20,-18 l20 m+28,32 d28 r24
u28"
2050 ALPHA$(26) = "c3 s10 bm+28,-24 u8 l60 d8 r40 m-44,44 d8 r62 u8 l40
m+42,-44"
2060 RETURN
```

```
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
' THIS PROGRAM DISPLAY SIMULATED FOVEAL VISUAL SEARCH '
' PATTERN FROM EXPERIMENTAL DATA. '
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
1000 COMMON JOY!()
1010 CLS
1020 OPTION BASE 1
1030 DIM ALPHA$(26)
1040 DIM JOY!(10000)
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
' CALIBRATION VALUES FOR VIEW WINDOW AND JOYSTICK '
' COORDINATES. '
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
1050 DX = 6: DY = 3
1060 XMAX = 245: YMAX = 245
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
' SUBROUTINE CONTAINING SET OF GRAPHIC LETTERS, '
' STRING VARIABLES. '
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
1070 GOSUB 1430
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
' SCALING OF VIEW WINDOW AND JOYSTICK COORDINATES '
' FOR GRAPHIC MODE SCREEN.EXPERIMENTAL DATA DISPLAY. '
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
1080 XSCALE = 640 / XMAX: YSCALE = 200 / YMAX
1090 PRINT "ENTER NAME OF FILE"
1100 INPUT F$
1110 SCREEN 2
1120 OPEN F$ FOR INPUT AS #1
1130 COUNT = 3
1140 INPUT #1, JOY(1), JOY(2)
1150 ID = JOY(1)
1160 ANG = JOY(2)
1170 LETTER$ = ALPHA$(ID)
1180 ROT$ = STR$(ANG)
1190 ARG$ = "ta" + ROT$ + LETTER$
1200 DO UNTIL EOF(1)
1210 INPUT #1, JOY(COUNT), JOY(COUNT + 1)
1220 X = JOY(COUNT)
1230 Y = JOY(COUNT + 1)
1240 X = INT(X * XSCALE)
1250 Y = INT(Y * YSCALE)
1260 X1 = X - DX: Y1 = Y - DY: X2 = X + DX: Y2 = Y + DY
```

```
1270 LINE (X1, Y1)-(X2, Y2), , B
''''''''''''''''''''''''''''''''''''''''''''''''''
' COUNTER FOR SPEED CONTROL OF THE VIEW WINDOW.   '
'                                   '
''''''''''''''''''''''''''''''''''''''''''''''''''
1280 FOR J = 1 TO 5
1290 DRAW "bm 320,100"
1300 DRAW ARG$
1310 NEXT J
1320 LINE (X1, Y1)-(X2, Y2), 0, B
1330 A$ = INKEY$: IF A$ <> "" THEN 1360
1340 COUNT = COUNT + 2
1350 LOOP
1360 CLOSE 1
1370 SCREEN 0
1380 PRINT " DO YOU WANT TO RECREATE ANOTHER TEST?(Y/N)"
1390 INPUT "", R$
1400 IF R$ = "Y" THEN GOTO 1090
1410 STOP
1420 END
''''''''''''''''''''''''''''''''''''''''''''''''''
' SUBROUTINE OF STRING VARIABLES.                 '
''''''''''''''''''''''''''''''''''''''''''''''''''
1430 ALPHA$(1) = "c3 s10 BM+10,+10 m+8,18 r20 m-32,-60 l20 m-32,60 r20
m+8,-18 r28 bm-4,-8 l20 m+10,-18 m+10,+18 "
1440 ALPHA$(2) = _
"c3 s10 bm +20,-30 l40 d60 r40 bm+0,-8 l24 u18 r20 bm +0,-10 l20 u16 r20 m+5,1
m+5,2 m+3,2 d7 m-3,2 m-2,1 m-3,1 m-3,1 m-2,0 bm-0,10 m+5,1 m+5,2 m+3,2 d9
m-3,2 m-2,1 m-2,1 m-3,1 bm-0,8 m+9,-1 m+3,-1 m+3,-1 m+3,-1 m+4,-2 m+4,-3
m+2,-3 m+1,-3 u6 m-1,-3 m-2,-3 m-4,-3 m-4,-2 m-3,-1 m+2,-1 m+2,-1 m+2,-1
m+2,-1 m+3,-2 m+2,-2 m+1,-3 m+1,-3 u3 m-1,-3 m-2,-3 m-4,-3 m-4,-2 m-3,-1 m
-3,-1 m-3,-1 m-4,-1 m-2,-0 m-2,0" _

1450 ALPHA$(3) = _
"c3 s10 bm+10,20 bm+0,-44 m-1,-2 m-3,-4 m-4,-3 m-3,-1 m-3,-1 l43 m-2,+0
m-3,+1 m-3,+1 m-4,+3 m-3,+3 m-1,+3 d44 m+2,+3 m+3,+3 m+4,+3 m+3,+1
m+3,+1 m+2,0 r43 m+3,-1 m+3,-1 m+4,-3 m+3,-4 m+1,-2 l20 m-2,+2 m-2,+1
m-2,+1 l19 m-2,-1 m-2,-1 m-3,-2 u43 m+3,-2 m+2,-1 m+2,-1 r19 m+2,+1 m+2,+1
m+2,+2 r19" _

1460 ALPHA$(4) = _
"c3 s10 bm +12,28 l28 u60 r28 bm+0,8 l12 d44 r12 S5 M+20,-2 M+20,-2 M+10,-4
M+10,-6 M+6,-8 M+4,-10 U28 M-4,-10 M-6,-8 M-10,-6 M-10,-4 M -20,-2 m-20,-2
```

```
bm +0,-16 m+20,+2 m+20,+2 m+18,+4 m+12,4 m+10,4 m +8,4 m+6,4 m+4,4
m+2,4 m+2,4 d39 m-2,4 m-2,4 m-2,4 m-2,4 m-4,4 m-4,4 m-6,4 m-8,4 m-10,4
m-12,4 m-18,4 m-20,2 m-20,2" _

1470 ALPHA$(5) = "c3 s10 u8 l24 u16 r40 u8 l60 d60 r60 u8 l40 u20 r24"
1480 ALPHA$(6) = "c3 s10 u8 l24 u16 r40 u8 l60 d60 r20 u28 r24 "
1490 ALPHA$(7) = _
"c3 s10 bm+16,20 bm+0,-44 m-1,-2 m-3,-4 m-4,-3 m-3,-1 m-3,-1 l43 m-2,+0
m-3,+1 m-3,+1 m-4,+3 m-3,+3 m-1,+3 d44 m+2,+3 m+3,+3 m+4,+3 m+3,+1 m+2,0
r44 m+3,-1 m+3,-1 m+4,-3 m+3,-4 m+1,-2 u16 l30 d8 r12 d8 m-2,+2 m-2,+1
m-2,+1 l19 m-2,-1 m-2,-1 m-3,-2 u43 m+3,-2 m+2,-1 m+2,-1 r19 m+2,+1 m+2,+1
m+2,+3 r19" _

1500 ALPHA$(8) = "c3 s10 d25 r20 u60 l20 d25 l32 u25 l20 d60 r20 u25 r32"
1510 ALPHA$(9) = "c3 s10 d30 l20 u60 r20 d30  "
1520 ALPHA$(10) = _
"c3 s10 bm +0,14 u44 r20 d44 s5 m-0,1 m-1,2 m-1,3 m-1,4 m-2,3 m-3,3 m-4,3
m-5,3 m-6,3 m-7,3 m-8,3 m-9,3 m-12,3 m-15,0 m-12,-2 m-9,-2 m-8,-2 m-8,-3
m-8,-3 s5 m-8,-6 m-6,-12 m-0,-10 r35 m+0,+10 m+6,+8  m+8,+2 m+8,+2 s5
m+12,0 m+8,-2 m+4,-2 m+4,-2 m+2,-2 m+3,-8" _

1530 ALPHA$(11) = "c3 s10 bm+20,32 r20 m-22,-40 m+22,-20 l20 m-28,24 u24
l20 d60 r20 u18 m+10,-8  m+18,26  "
1540 ALPHA$(12) = "c3 s10 d20 r40 d8 l60 u60 r20 d40"
1550 ALPHA$(13) = "c3 s10 m+24,-34 r20 d60 l20 u34  m-20,34 l8 m-20,-34 d34
l20 u60 r20 m+24,34"
1560 ALPHA$(14) = "c3 s10  U36 R20 D60 L20 M-36,-36 D37 l20 u60 r20
m+36,36"
1570 ALPHA$(15) = _
"c3 s10 bm +16,20 u44 bm -20,0 d43 bm-32,0 u43bm-20,0  d44 m+2,+3 m+3,+3
m+4,+3 m+3,+1 m+3,+1 m+2,0 r43 m+3,-1 m+3,-1 m+4,-3 m+3,-4 m+1,-2
bm-21,-1 m-2,+2 m-2,+1 m-2,+1 l19 m-2,-1 m-2,-1 m-3,-2 bm-0,-43 m+3,-2 m+2,-1
m+2,-1 r19 m +2,+1 m+2,+1 m+2,+2 bm +20,0 m-1,-2 m-3,-4 m-4,-3 m-3,-1 m-3,-1
l43 m-2,+0 m-3,+1 m-3,+1 m-4,+3 m-3,+3 m-1,+3 " _

1580 ALPHA$(16) = _
"c3 s10 bm+20,0 l20 d26 l20 u60 r36 bm+0,8 l18 d16 r18 S5 M+6,-1 M+6,-1
M+4,-1 M+2,-2 M+2,0 M+2,-3 S5  M+2,0 M+2,-3  m+1,-4 m+1,-3 m-1,-4  m-1,-4
m-2,-3 m-2,0 m-2,-3 m-2,0 m-2,-2 m-4,-1 m-6,-1 m-6,-1  bm +8,52 s10 m+5,-1
m+5,-1 m+4,-1 m+2,-2 m+2,0 m+2,-3 m+2,0 m+2,-3  m+1,-3 m+1,-4 m-1,-4
m-1,-4 m-2,-3 m-2,0 m-2,-3 m-2,0 m-2,-2 m-5,-1 m-7,-1 m-7,0" _

1590 ALPHA$(17) = _
```

```
"c3 s10 bm +16,20 u44 bm -20,0 d43 bm-32,0 u43bm-20,0 d44 m+2,+3 m+3,+3
m+4,+3 m+3,+1 m+3,+1 m+2,0 r41  m +10,6 m+9,-4  m-8,-5 m+3,-4 m+1,-2
m+1,-2 bm -21,-1 m-2,+2 m-2,+1 m-2,+1 l19 m-2,-1 m-2,-1 m-3,-2 bm-0,-43
m+3,-2 m+2,-1 m+2,-1 r19 m+2,+1 m+2,+1 m+2,+2 bm+20,0 m-1,-2 m-3,-4 m-4,-3
m-3,-1 m-3,-1 l43 m-2,+0 m-3,+1 m-3,+1 m-4,+3 m-3,+3 m-1,+3" _

1600 ALPHA$(18) = _
"c3 s10 bm +0,14 u44 r20 d44 s5 m-0,1 m-1,2 m-1,3 m-1,4 m-2,3 m-3,3 m-4,3
m-5,3 m-6,3 m-7,3 m-8,3 m-9,3 m-12,3 m-15,0 m-12,-2 m-9,-2 m-8,-2 m-8,-3
m-8,-3 s5 m-8,-6 m-6,-12 m-0,-10 r35 m+0,+10 m+6,+8  m+8,+2 m+8,+2 s5
m+12,0 m+8,-2 m+4,-2 m+4,-2 m+2,-2 m+" _

1610 ALPHA$(19) = "c3 s10 bm+28,-24 u8 l60 d8 r40 m-44,44 d8 r62 u8 l40
m+42,-44"
1620 ALPHA$(20) = "c3 s10  u26 r20 u8 l60 d8 r20 d52 r20 u26"
1630 ALPHA$(21) = "c3 s10 bm +16,20 u44 l20 d43 bm-32,0 u43 l20 d44 m+2,+3
m+3,+3 m+4,+3 m+3,+1 m+3,+1 m+2,0 r43 m+3,-1 m+3,-1 m+4,-3 m+3,-4 m+1,-2
bm-21,-1 m-2,+2 m-2,+1 m-2,+1 l19 m-2,-1 m-2,-1 m-3,-2"
1640 ALPHA$(22) = "c3 s10 m+22,-38 r20 m-32,60 l20 m-32,-60 r20 m+22,38"
1650 ALPHA$(23) = "c3 s10 m+14,32 r20 m+20,-60 l20 m-12,32 m-12,-32 l20
m-12,32 m-12,-32 l20 m+20,60 r20 m+14,-32"
1660 ALPHA$(24) = "c3 s10 m+24,-28 l20 m-16,18 m-16,-18 l20 m+24,28 m-24,28
r20 m+16,-18 m+16,18 r20 m-24,-28"
1670 ALPHA$(25) = "c3 s10 m+28,-32 l20 m-20,18 m-20,-18 l20 m+28,32 d28 r24
u28"
1680 ALPHA$(26) = "c3 s10 bm+28,-24 u8 l60 d8 r40 m-44,44 d8 r62 u8 l40
m+42,-44"
1690 RETURN
```

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