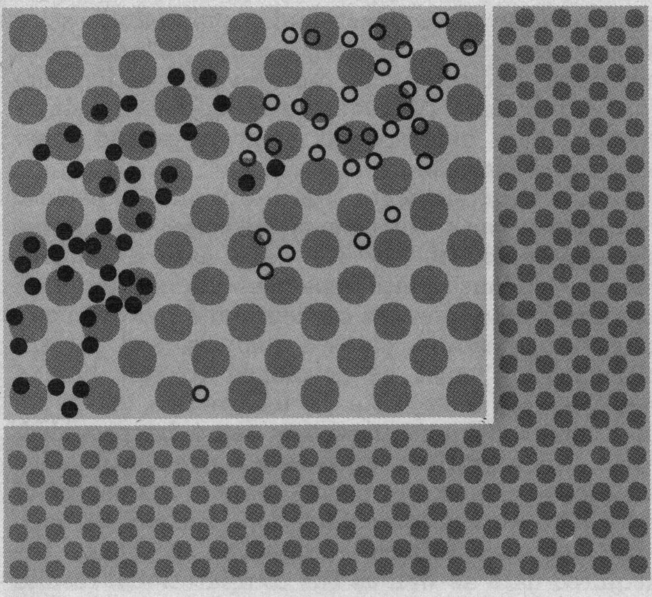

Interactive Pattern Recognition: Techniques and Systems

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Introduction

Pattern recognition is not a new subject. Its principles and methodologies have influenced the course of technological development for many years in almost every knowledge-based field. To some fields, pattern recognition is a major tool for problem-solving, capable of producing dramatic results. To others, it has been accompanied by failure and disappointment. Despite the mixed results, however, pattern recognition has continued to be a fascinating field of research and development in its own right. This is evidenced by the growing list of activities, academic and industrial alike, relating to pattern recognition work.

There are at least two reasons for this continued interest. First, pattern recognition, unlike pure mathematics for example, is a field of abstraction as well as of experimentation. Often this leads to more fruitful applications which in turn stimulate further research and development. The second reason is that, as in any other modern technology, pattern recognition has been very much a product of today's computer technology. Each of the new advances in computer technology—automatic programming, parallel computation, graphics, microprocessors, etc.—has been accompanied by new concepts and methods in pattern recognition work. This article focuses on the relationship between pattern recognition and a particular area of computer technology—interactive graphics.

Until recently, computers have been used in pattern recognition work largely for the purpose of simulating or testing computational procedures before they are implemented in hardware. Typically, in this environment, the role of a computer and that of a designer are passive and non-interactive. The evolving use of computer graphics, however, has changed these roles significantly. With the assistance of graphics and other interactive media, both the computer and the human can participate in the pattern recognition process simultaneously and interactively. Like many other computer-aided systems, this interactive approach allows the speed and accuracy of a computer to be combined with human ability and intuition at various stages of the pattern recognition work. It is particularly useful when one is faced with a large data base of which analytic and statistical characteristics must be calculated dynamically and in real time. In the event of minimum prior knowledge regarding the data base, human-machine interplay via some graphical medium often becomes a necessity.

What is Interactive Pattern Recognition (IPR)?

Before we discuss the need for an interactive approach in more detail, what we mean by "the pattern recognition problem" should be made clear. Three interrelated but clearly distinct processes take place in a typical pattern recognition task: data acquisition, pattern analysis, and pattern classification.

Data acquisition is the process of converting the data from its physical source (speech, pictures, character strings, etc.) into a form acceptable to the machine (computer or other computing device) for further processing. Sensors, scanners, and digitizing facilities are among those needed to perform the data acquisition task.

Once data have been collected, the process of data analysis begins. The general intent of this process is simply to learn about the data, determine the different events or pattern classes that might exist in the data, and organize the body of learned knowledge into a form most efficient for further processing. Some of the typical tasks are feature extraction, feature selection, and cluster analysis.

The third process is classification. Its purpose is to decide, based on the information obtained from the analysis process, how to put a new, unknown data sample into one of the known classes in the best way possible. The design of recognition logic with some "specified" performance is often the key task of this classification process.

We have deliberately refrained from labeling the classification process as the *last* of the three to take place in a pattern recognition problem. Often the three processes must relate to one another and they must be carried out in a mixed order requiring iteration and interaction. For instance, the results of pattern classification may well suggest a critical parameter in the data analysis or data acquisition process to be changed. This change could also subsequently lead to a modification in the classification procedure. Many iterations of this process-to-process interaction may be required before the pattern recognition problem is satisfactorily solved. Clearly, the execution of this interaction and iteration cannot be effectively carried out without the participation of a human.

Elements Influencing Pattern Recognition. The need to take an interactive approach can be examined by considering the elements that influence the pattern recognition problem. Three of the most critical elements are (a) the amount of data, (b) computer technology, and (c) people—the designer and the user.

One of the most pressing tasks in pattern recognition work today is to develop systems that are capable of handling massive amounts of data. As new and more economical methods of data acquisition are developed, a greater number and a wider variety of disciplines place emphasis on quantification, thus creating ever larger amounts of data. Unfortunately, even with the advances in computing technology, much of the collected data cannot be adequately analyzed. Moreover, the traditional view of achieving a high ratio of data compression as the process of data analysis progresses no longer holds true. Increasingly sophisticated methods of analysis often involve a volume of output much greater than the original body of data. To alleviate these problems, the data acquisition and analysis processes must be carefully controlled by an interactive environment in which the computer graphics facility, for instance, provides the human with the requisite level of visual control over the two processes.

The influence on pattern recognition of computer hardware and software has always been substantial in the past. Many of the design concepts in pattern analysis and classification have been under the limitation of an orthodox general purpose machine. This limitation, however, can be easily removed with the advent of new computing technology. For example, a parallel arithmetic and memory access capability, combined with data transfer organization specifically designed to perform such tasks, would be far more important in a pattern recognition problem than the conventional sequential access to a random access memory. Such influences of computer technology on pattern recognition, unfortunately, have been slow in coming until today's revolutionary development in graphics and other interactive facilities.

Of the three elements that influence the pattern recognition work, the element of people is perhaps the most critical. By its very nature, pattern recognition must relate to people—i.e., the designer, the user. Therefore, the concepts and methodology of data acquisition, pattern analysis, and pattern classification must be developed to suit human requirements and talents. To achieve this, two types of human-machine interaction must be provided. First, it is essential to provide a convenient facility for interaction among people. This is the aspect of human-to-human communication. Second, at each stage of the pattern recognition problem, the acquired data as well as the computational results from analysis and classification must be matched to capabilities of the people. This is the aspect of human-to-machine communication. Both aspects of communication need to be structured in order to strengthen human judgement and intervention.

A Model of IPR. When we speak of interactive pattern recognition, we are referring to some form of human participation in one or more of the three processes of a pattern recognition problem. The three processes and the human element constitute an interactive system for pattern recognition. This situation is depicted in Figure 1.

In a typical interactive system, a person is seated at a terminal, usually with a graphical display and/or other interactive facilities. He works with the computer in an attempt to collect the relevant data, to extract the characteristic information from the data, or to synthesize the recognition logic for pattern classification. His ultimate goal is to improve the performance of the three processes by interacting with the computer and his data. In the simplest case, this interaction may involve the person as a clerk, being "asked" by the computer to check on the input if a decision as to its class membership cannot be made. Or the person, acting as a supervisor, may be asked to provide the "names" for the input data the computer has classified in order to determine the correctness of these classifications. On the other extreme, human assistance may be used as part of the data analysis and classification processes. That is, the person at the terminal may be helping discover and evaluate the characteristics that are most informative to the classification process. He may also initiate and later modify the classification algorithms to be used by the recognition logic. Using the computer and its associated graphical facilities, he may try various classification techniques as he goes along, calling on the computer when needed to give him a certain two-dimensional display of the information on hand. This information may include the original data input or any intermediate results of partial analysis of the data.

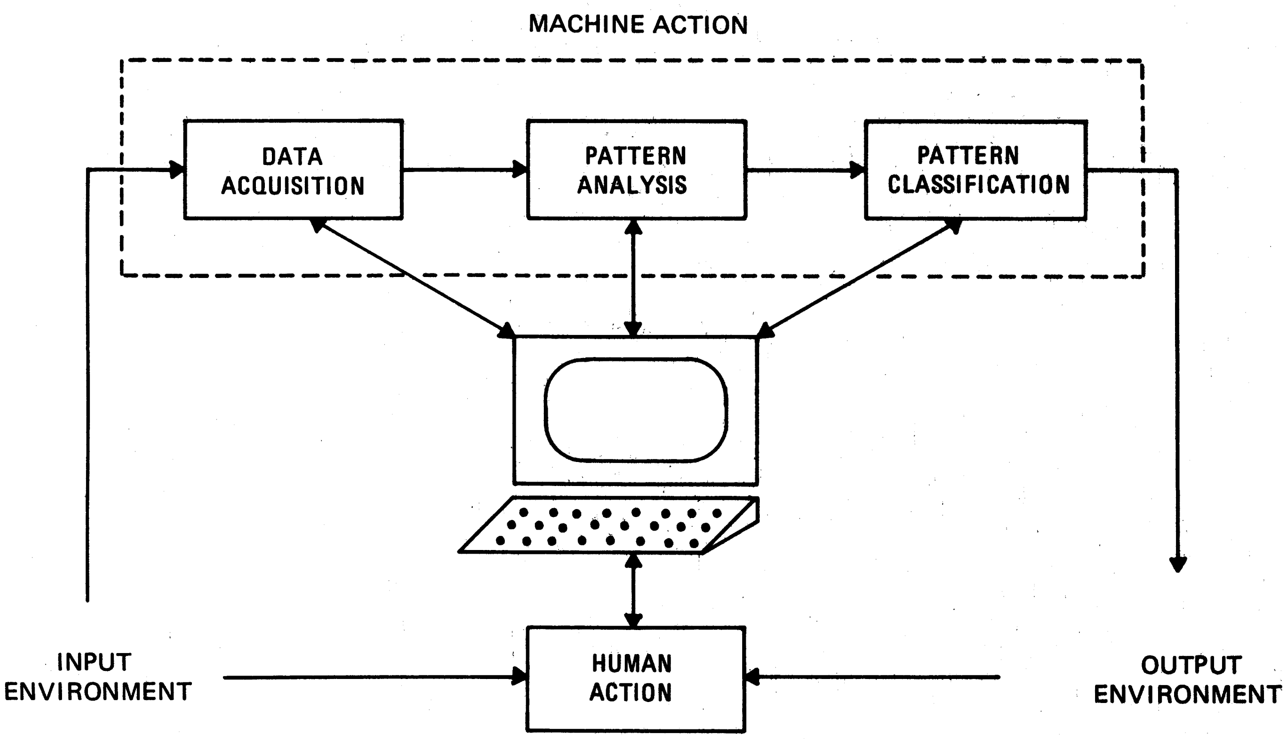

Figure 1. Typical configuration of an interactive pattern recognition system

Much of the work in interactive pattern recognition to date seems to have one or more types of the activities just described. Depending upon the goals that a particular system is designed to achieve, each system has proven to be useful in that, in addition to doing old things differently, it can use the new medium to do things better. Applications of interactive pattern recognition systems have been found particularly in those areas where automated means for information processing and decision-making often require human assistance. Some of these applications will be discussed in a later section.

General Considerations of IPR

Interactive pattern recognition presents special problems of its own. Some of the problems are attributable to the added capabilities of a pattern recognition system involving human-machine interaction. Other problems are due to design considerations not uncommon to conventional pattern recognition systems.

Basic Characteristics. Depending upon the goals and applications, an interactive system for pattern recognition has one or more of the following characteristics:

Graphical Presentation. The key ingredient of interactive pattern recognition is the use of computer graphics in presenting useful information of the data to the human. Graphical presentation is perhaps the most effective way of insightful pattern analysis. There are several reasons for this. First, the human eye and brain are speedy and proficient in recognizing certain types of geometric configurations. This is certainly very useful in such analysis tasks as detecting outlyers, discovering clusters, etc. Second, a good graphical presentation can serve to display clearly and effectively a pattern or event imbedded in quantities of data whose calculation or observation is far from simple. A picture is not merely worth a thousand words. When properly constructed, it is much more easily absorbed than words or numbers can be read. Large volumes of data can be summarized and exposed economically by a single graphical representation. Some of the display-oriented algorithms and techniques discussed in later sections will illustrate this point.

Online and Real Time. This property is one of the most obvious advantages of interactive systems to a pattern recognition worker who has experienced frustrations in a non-interactive environment. In an interactive setting, the human can communicate with his data as well as results of analysis and classification dynamically and almost instantaneously. This allows continuation of work on a problem without the loss of a train of thought.

Iteration and Interaction. Work in pattern analysis and design of classification logic must be iterative to be effective. At almost every stage of these processes, human judgement is required. This judgement must be based upon the information about what has been found and must relate to the next stage for what might be expected. Iteration allows

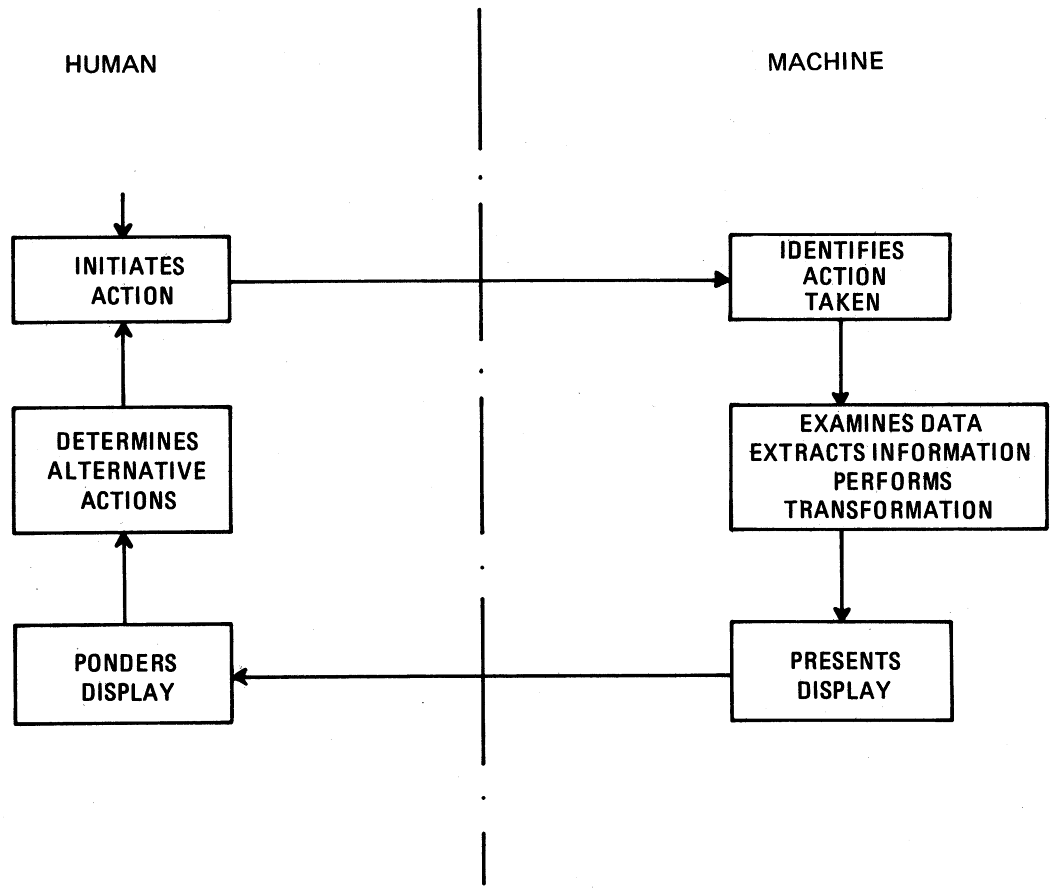

Figure 2. Iteration and interaction in a typical interactive system for pattern recognition

the human mind to be informed by accumulating the past knowledge learned. An interactive system provides the flexibility needed to achieve effective, human-directed iteration. Figure 2 shows how iterative and interactive actions take place in a typical interactive system for pattern recognition.

Flexibility in Viewpoint and Approach. An interactive system with a variety of optional pattern analysis and classification algorithms allows the user to try different methods to solve a particular problem. It provides the flexibility in viewpoint as well as in approach. In addition to having access to powerful computing facilities, the human is given the flexibility in the forming of hypotheses, in the choice of a model to fit the hypothesis formed, in the data to be used in carrying out testing and evaluation, and in choosing the various techniques and algorithms for calculations required in analysis and classification. Flexibility of this kind is crucial to making steady progress in the three processes of pattern recognition. The more flexibility we have and the more conveniently it can be used, the faster our progress will be.

Abstraction and Experimentation. In an interactive system, the traditional, arbitrary line between theories and experiments need not be drawn, since both can be explored with one facility. The designer is no longer needlessly concerned with whether the presumed structure of data fits the hypothesis of the theoretical model. Appropriate experiments can be easily performed to check out the validity. Depending on the results of experimentation, the hypothesis is retained, discarded, or modified, leading perhaps to a new theoretical model.

In summary, an interactive system allows a pattern recognition problem to take advantage of the capabilities of the machine as well as those of the human. It helps the marriage between theory and experimentation. All this is accomplished by a flexible, online system for convenient visual feedback, knowledge-based iteration, and other forms of human-machine interaction.

Design Considerations. Two considerations are important in implementing a system for interactive pattern recognition. First, from the human side of the problem comes the consideration of making the graphical representation of information most suitable for human examination. Second, from the machine side of the problem, we must consider the most efficient configuration for both the hardware and software required to support the system.

Graphical Representation. Current facilities for display and real-time, online interaction have developed substantially beyond our ability to use them effectively in pattern recognition work. In designing methods for effective graphical presentation, we

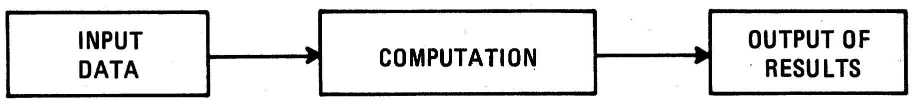

Figure 3a. Non-interactive systems

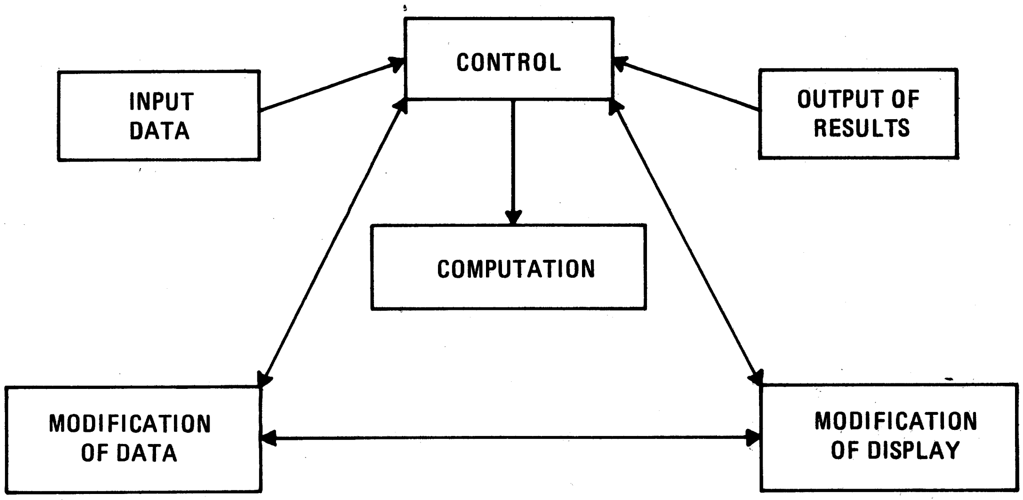

Figure 3 b. Interactive systems

Figure 3. Comparison of software structures

must distinguish between two modes of display: display of *data* and display of *information*. The former mode is simply a naive presentation of what the original data look like. A display of an image in terms of its two-dimensional array is one such example. Displays of this type are often very useful, but more sophisticated techniques which display the "information" contained in the data or in the results of analysis can be more economical and revealing. This latter mode of display will be the focus of our discussion in the next section.

Computing Facilities. The consideration of what computing facilities are needed to support interactive pattern recognition work is not unlike that of other interactive computing systems. We can identify three areas of importance and briefly outline their role in a pattern recognition problem.

• System Consideration. Two types of configurations are possible. One is a large-scale computer with multiprogramming and/or timeshared capability. This configuration is usually more powerful and accessible to more people. Most of the general-purpose systems for interactive pattern recognition are of this type. The other configuration is based upon a small machine, with an option to be linked to a large computer. There is now growing evidence that the rapidly diminishing cost and size of smaller computers (mini- and microcomputers) make this configuration more popular. The increasing power and ease with which smaller computers can be tailored to specific applications is also a favorable consideration.

• Hardware Facility. In addition to the primary computing facility (a computer), one or more of the following graphical capabilities must be provided: (a) machine-to-human communication—e.g., displays, plotters, etc., and (b) human-to-machine communication—e.g., lightpen, tablet, keyboard, etc.

• Software Facility. An interactive system must involve two types of software efforts:

(a) Functional software. This refers to the entire collection of programs needed to support the computational and manipulative functions required in the system. Examples are the extensive data manipulation programs for pattern analysis. A wide variety of programs for mathematical and graphic techniques is another example.

(b) Controlling software. The potential of any interactive system hinges on how various programs relate to one another as well as to the human. This requires an extremely flexible and well organized executive system—a piece of software that controls the rest.

Figure 3 depicts a typical software structure in an interactive environment as compared to that of a conventional, noninteractive system.

Display-Oriented Techniques

Interactive pattern recognition must rely upon computer graphics in order to derive and transfer useful information. However, the problems encountered in pattern recognition are considerably different from those in other areas of application involving the use of computer graphics. In a typical graphics task, one deals with solid objects and/or continuous surfaces.[5] Standard graphics techniques, therefore, place emphasis on the display and manipulation of these objects and surfaces. These techniques are useful, but are not adequate for the analysis and manipulation of multidimensional data often encountered in a pattern recognition problem. This section briefly discusses some of the techniques suitable for interactive pattern analysis and classification.

One of the most important tasks of pattern analysis is to determine, from a set of multivariate data, whether and how vectors in the data are grouped into various clusters. In an interactive environment, this can be accomplished by presenting the data in a form suitable for computer display and human observation. This means that we must develop algorithms for mapping high-dimensional vectors into a two-dimensional space.* Algorithms that perform this kind of mapping are said to be *display-oriented.*

In order to describe the various algorithms in a unified manner, the following notation will be used. Assume that we have a set of N pattern samples. Each of the N samples is represented by an h-dimensional vector in the h-space. These N vectors are denoted by X_i, i = 1, 2, . . . , N, where

$$X_i = \begin{bmatrix} X_{i1} \\ X_{i2} \\ \cdot \\ \cdot \\ \cdot \\ X_{ih} \end{bmatrix} = [X_{i1}, X_{i2}, \ldots, X_{ih}]^t$$

and t denotes the transpose operation. Let the mapping in question be denoted by T. The mapping T transforms each X_i into a two-dimensional vector in the two-space for computer display. Thus, corresponding to the N vectors X_i, we have the N vectors in the two-space designated by Y_i, i = 1, 2, . . . , N, where

$$Y_i = T(X_i) = \begin{bmatrix} Y_{i1} \\ Y_{i2} \end{bmatrix} = [Y_{i1} Y_{i2}]^t$$

Linear Mappings. This class of mappings performs linear transformations on the set of X_i's (or on other characteristic representations of the X_i's) to produce the set Y_i's. There are two widely used techniques: principal components analysis and multiple discriminant analysis.

Principal Components. In this method, the mapping T is composed of the first two eigenvectors calculated from one of the two matrices:

1) The scatter matrix $S = [S_{ij}]$ where

$$S_{ij} = \sum_{k=1}^{N} X_{ki} X_{kj} - N \bar{X}_i \bar{X}_j \quad i,j = 1, 2, \ldots, h$$

and $\bar{X}_i$ refers to the i^th^ component of the sample mean $\bar{X}$ for the N data vectors.

2) The covariance matrix $\Sigma = E[(X - \mu)(X - \mu)^t]$ if the N vectors are considered to be samples generated from a random vector X with mean μ and covariance matrix Σ . Σ and μ are calculated from the N data vectors.

Let $\lambda_1 \geqslant \lambda_2 \geqslant \ldots > \lambda_h$ be the eigenvalues and $P_1, P_2, \ldots, P_h$ be the corresponding eigenvectors of S or Σ. If we define the mapping T as the matrix consisting of the first two eigenvectors P_1 and P_2, i.e.,

$$T = [P_1 P_2], \text{ then}$$

$$Y_i = T^t X = \begin{bmatrix} P_1{}^t X_i \\ P_2{}^t X_i \end{bmatrix} = \begin{bmatrix} Y_{i1} \\ Y_{i2} \end{bmatrix}$$

A visual representation of the N h-dimensional points is then obtained by plotting the two y-coordinates (first and second principal components) for each vector Y_i.

A two-dimensional configuration determined by the principal components method described above has a number of useful properties.[7] Among them are the following:

1) It maximizes the sum of squares of inter-vector distances.

2) It preserves the spatial relation of vectors to the sample mean.

3) The principal components are uncorrelated, and the variance of the ith component is λ_i.

Whether this two-space representation can help determine clusters of vectors in the original h-space depends on how well the inter-vector configuration of the N vectors is preserved in the two-space. Unfortunately, there is no general method for measuring the cluster-seeking ability of the principal components technique.

Figure 4 shows a two-space display of the famous Iris data** using the principal components method.

*Three-dimensional configurations displayed as perspective views are also possible but will not be discussed in this paper.

**The Iris data[6] has been widely used in the literature for studying pattern recognition and cluster analysis techniques. It will be used for illustration purposes throughout this paper. The data base consists of 150 samples of four variables each. The variables are size measurements on various species of Iris: sepal length and width, petal length and width. Each sample has been classified into one of three groups: Setosa, Versicolor, and Virginica.

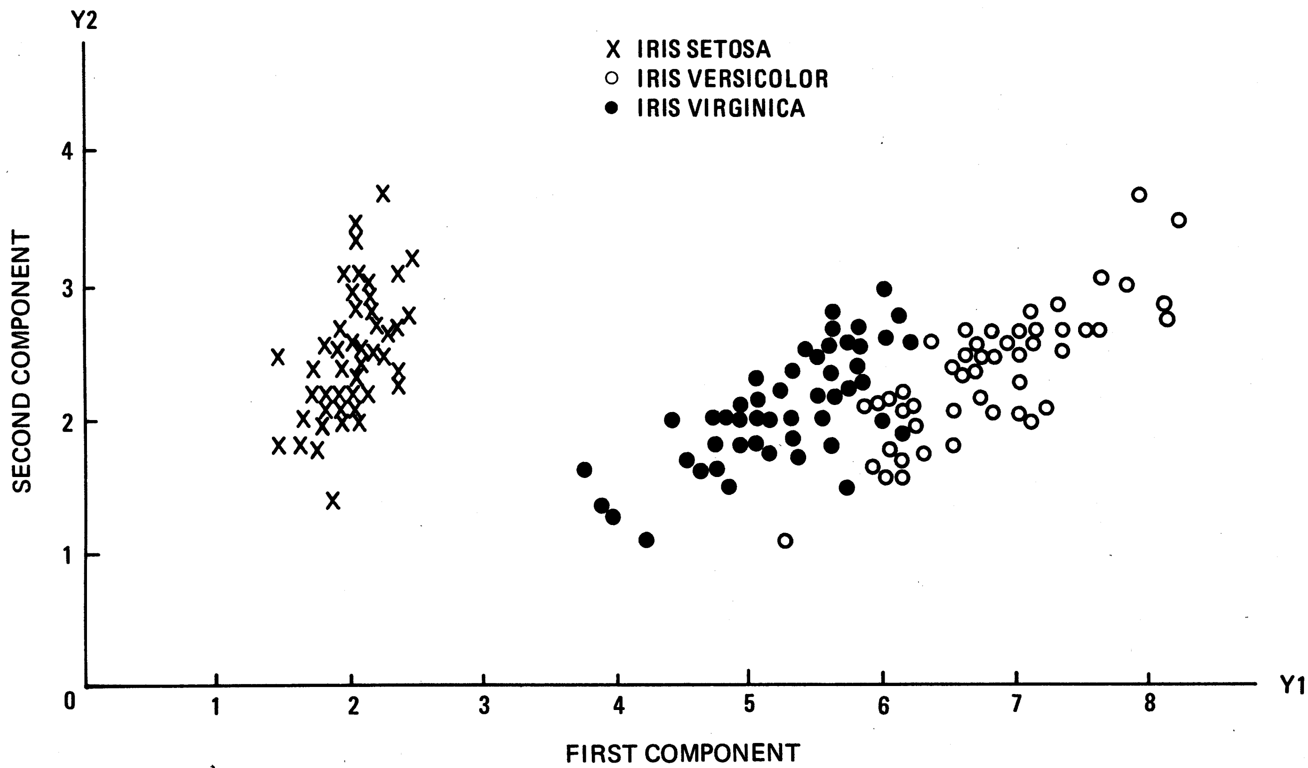

Figure 4. A two-dimensional display of the Iris data using the principal components method

Discriminant Analysis. This is perhaps the most widely used class of linear mappings in pattern recognition work. Linear mappings of this type emphasize the separation of classes that might exist in the data. In this method, we are interested in determining a mapping T such that the transformed vectors Y_i are maximally discriminated in the two-space. This can be achieved by maximizing a discriminant criterion R which is related to the ratio of the projected between-class differences to the sum of the projected within-class variability of the data. If B is the between-class scatter matrix and W the sum of the within-class scatter matrices computed from the N vectors X_i, then the desired mapping T is obtained by solving a generalized eigenvalue problem involving both B and W. In general, there are C-1 (where C is the number of classes) eigenvalues $\lambda_1 \geqslant \lambda_2 \ldots \geqslant \lambda_{C-1}$ and C-1 corresponding eigenvectors $P_1, P_2, \ldots, P_{C-1}$. These are called discriminant vectors. In order to display the data for interactive analysis, the first two discriminant vectors can be chosen to form a discriminant plane.

In the case where there are only two classes of data vectors ($C = 2$), the discriminant analysis method generates only one discriminant vector, P_1. This is the well-known Fisher discriminant vector. In order to project the data into a discriminant plane for display, however, a second vector, P_2, must be chosen. This vector may be found by maximizing the discriminant ratio R as before, but under the constraint that P_2 be orthogonal to P_1. These two vectors, P_1 and P_2, form the optimal discriminant plane for the graphical display of data involving two classes. An important application of this discriminant plane is when two groups of data are found difficult to discriminate in the original or the two-dimensional space (as in the case of Iris Vericolor and Iris Virginica of the Iris data). One may decide to project these two groups of data into the optimal discriminant plane for further analysis. Figure 5 shows a two-space display of the 100 samples of the two difficult Iris groups. Note that the two groups of data, which had an overlapping region in the previous display, are now linearly separable by a straight line in the discriminant plane.

Nonlinear Mappings. A nonlinear mapping reduces the dimensionality of the pattern vectors from h dimensions to two by means other than linear transformations. Under this mapping, we attempt to preserve the inherent structure of the data as much as possible while reducing the dimensionality. One way that this structure preservation can be achieved is by fitting the N h-dimensional vectors in the two-dimensional space so that their inter-vector distances (or other similar measures) approximate the corresponding inter-vector distances in the

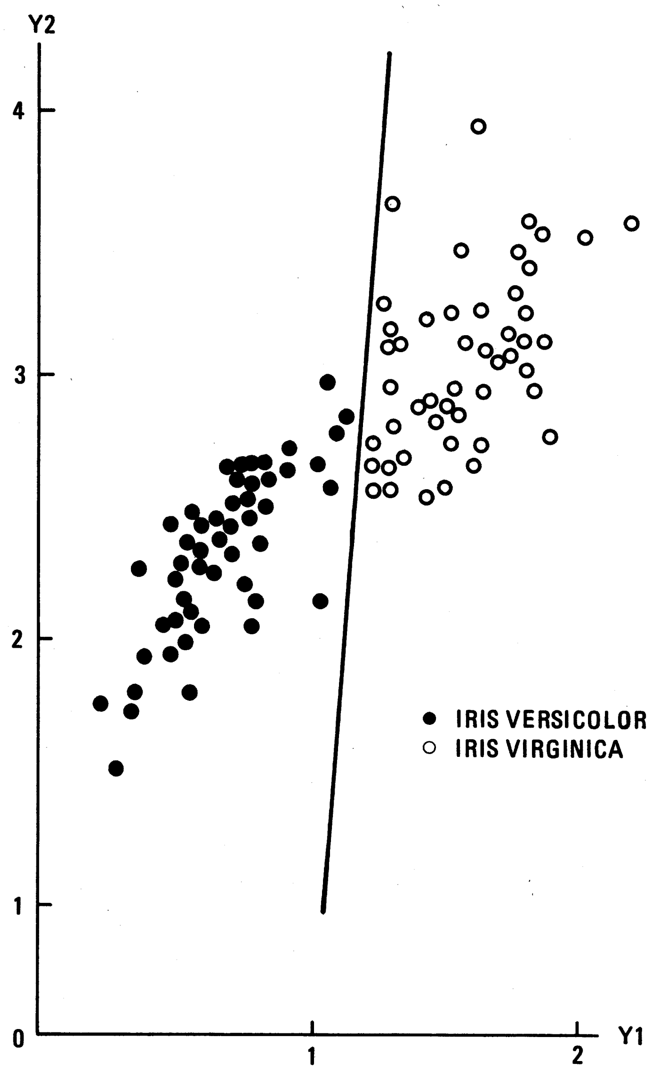

Figure 5. A two-dimensional display of two groups of the Iris data in the optimal discriminant plane

original h-space. Let us denote the Euclidean distance between the vectors X_i and X_j in the h-space by d^*_{ij} and the distance between Y_i and Y_j in the two-space by d_{ij}. We say that the structure of the data is strictly preserved under the nonlinear mapping T if for all i and j, $d^*_{ij} = d_{ij}$. Obviously, for all but the most trivial cases this strict preservation is impossible to achieve. We could, however, achieve various kinds of approximate preservation without much difficulty. The consequence of this approximation is of course the introduction of error, e_{ij}, where

$$e_{ij} = d^*_{ij} - d_{ij}$$

for some or perhaps all values of i and j.

All nonlinear mappings must deal with the problem of how preservation of the data structure (in the sense of d^*_{ij}) can be best achieved. Clearly, we need to choose an error function

$$E = f(e_{ij}) = f(d^*_{ij} - d_{ij})$$

so that the value of this function will reflect the degree of structural preservation of the mapping in question. Ideally, the error function E is monotonically related to the preservation—e.g., the smaller the value of E, the better the preservation. Once the error function has been chosen, an iterative search procedure may be used to find the "best" two-dimensional representation of the N h-dimensional vectors. A typical nonlinear mapping consists of a three-step algorithm:

Step 1—Choose an initial set of Y vectors. This set is referred to as the *initial configuration* of the two-space. It can be chosen by a random selection of the N Y's in the two-dimensional space or by some other means using the a priori knowledge of the data.

Step 2—Adjust the Y's of the present configuration, starting from the initial configuration. The adjustment is carried out in such a way that the next configuration (the set of the adjusted Y's) will have a smaller value of the error function. The transition from the present configuration to the next configuration is called an *iteration.*

Step 3—Repeat Step 2 until one of the three termination criteria is met: (a) E has reached a minimum value, (b) a predetermined number of iterations has been reached, or (c) the human observer is satisified with the present configuration.

Figure 6 shows a display of the two-dimensional representation of the same Iris data using a nonlinear mapping developed by Sammon.[12] Sammon's algorithm uses an error function that is proportional to the sum of squared individual errors, e_{ij}. A gradient search procedure is then applied to successively adjust the Y configurations.

The main advantage of the nonlinear mappings described here is that they are directly applicable to a display-oriented environment. One starts with an initial two-dimensional representation of the multivariate data and ends up with a final two-dimensional representation ready for computer display. Unlike the linear mappings, however, the iterative nature of the nonlinear mappings is computationally more involved. A number of various nonlinear mapping algorithms have been developed, and the references listed at the end of this article provide additional sources of discussion on this subject.

Functional Mappings. The purpose of these mappings is to transform the multivariable pattern vectors into functions of a single variable. These functions are then plotted against the single variable,

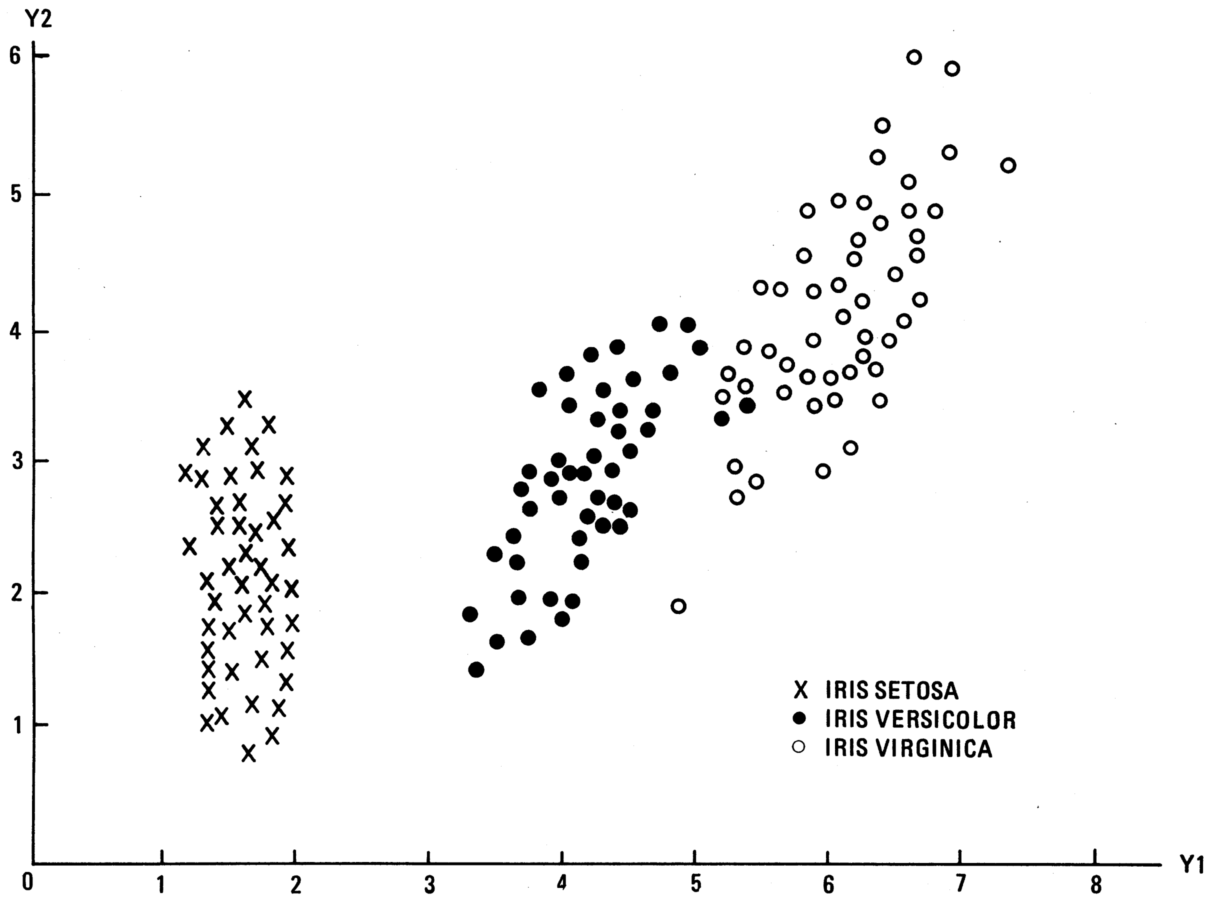

Figure 6. A two-dimensional display of the Iris data using Sammon's nonlinear mapping

presenting a two-dimensional view of the original data. If the class of transformations is properly chosen, such a presentation is capable of helping detect the clusters and select features as well as perform statistical analysis.

As an example, consider for each pattern vector X, the transformation

$$f_X(t) = \frac{1}{\sqrt{2}} X_1 + X_2 \text{ Sin } t + X_3 \cos t + X_4 \text{ Sin } 2t$$

$$+ X_5 \cos 2t + \ldots + \begin{cases} X_h \text{ Sin } (h/2)t & \text{if } h \text{ is even} \\ X_h \text{ Cos } (h-1/2)t & \text{if } h \text{ is odd} \end{cases}$$

$$\text{for } -\pi \leqslant t \leqslant \pi$$

For each X, its corresponding $f_x(t)$ as defined above may be plotted against the variable t between the interval $[-\pi, \pi]$. Since the human is accustomed to examining functional plots of this type, they may be beneficial as an aid for analyzing, as well as classifying, high-dimensional data with a graphical display. Andrews[16] has shown that these functional plots have several important mathematical and statistical properties. One such property, especially useful from the standpoint of interactive pattern analysis and classification, is that the functional mapping defined above preserves distances. This means that pattern vectors that are "close" in the original h-space will appear as two close functions in the functional space, and vice-versa. Thus, clusters in the data may be visually identified from the functional plots. Also, pattern vectors that do not belong to a particular class (cluster) can be easily detected. Figure 7(a) shows the functional plots of three mean vectors of the same Iris data. The clustering property of this mapping is illustrated in Figures 7b thru 7d.

Additional properties of this functional mapping as well as other functional mappings with applications to interactive pattern recognition work can be found in the references listed at the end of this article.

Pictorial Mappings. High-dimensional pattern vectors may be presented pictorially for graphical display and human examination. The intent of these mappings is to transform the multivariate data into "pictures" of some kind that more easily permit the

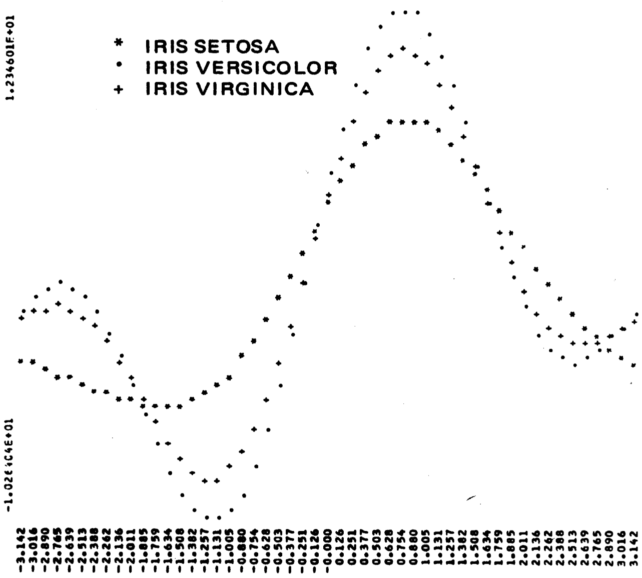

Figure 7 a. **Mean vectors of the three Iris groups**

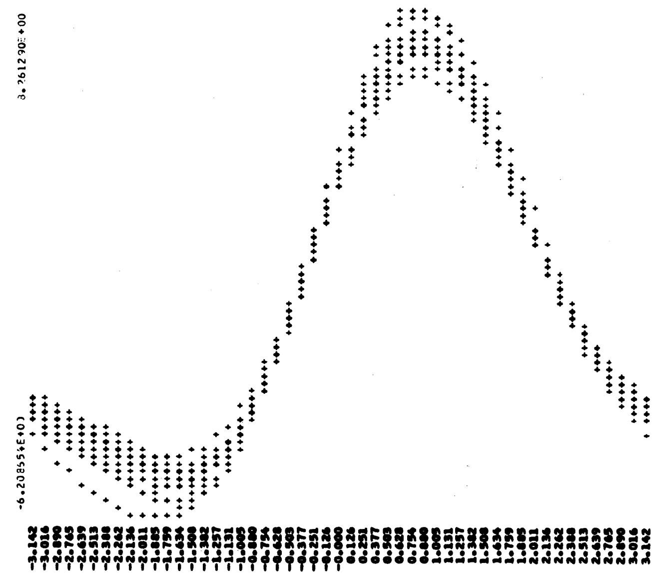

Figure 7 b. **Functional cluster showing 10 samples from Iris Setosa**

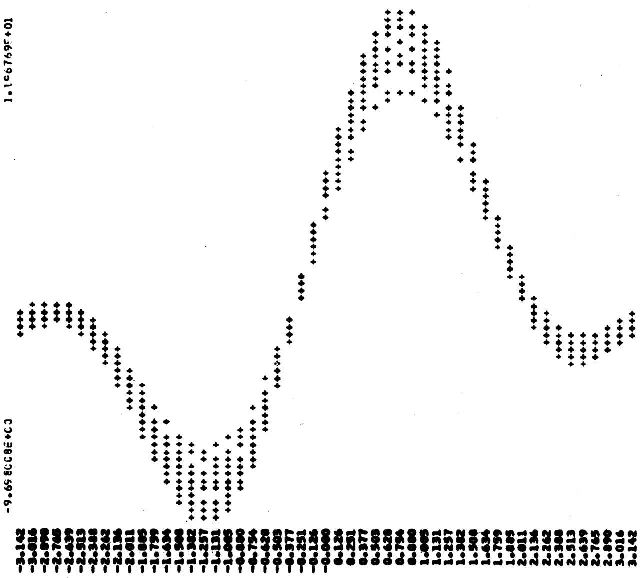

Figure 7 c. **Functional cluster showing 10 samples from Iris Versicolor**

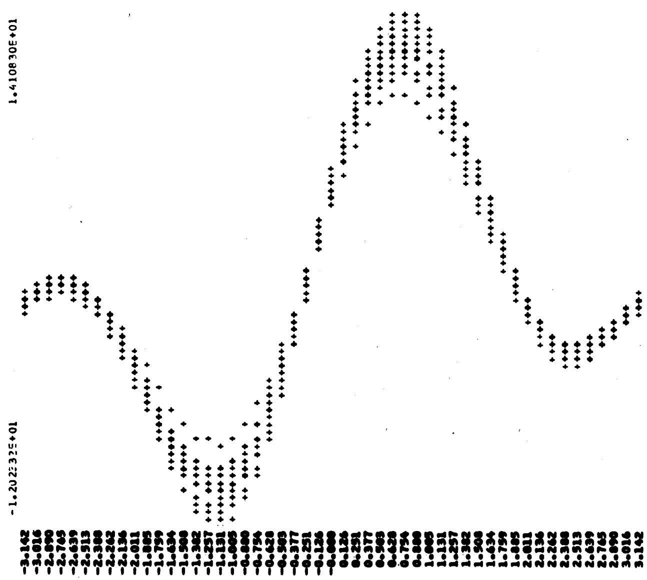

Figure 7 d. **Functional cluster showing 10 samples from Iris Virginica**

Figure 7. Functional display of multi-dimensional data

human to perform visual analysis. One such method, invented by Chernoff,[18] is to transform each pattern vector into a cartoon face. The parameters of the face, such as length of nose and size of eyes, correspond to the variables of the vector. A collection of pattern vectors is represented by a collection of faces.

To illustrate the method, consider the Iris data used in the previous illustrations. Each data vector has four variables corresponding to four parameters of a face as follows:

Original Variables		*Parameters of Face*	
X_1	sepal length	Y_1	length of nose
X_2	sepal width	Y_2	size of eyes (radius)
X_3	petal length	Y_3	separation of eyes
X_4	petal width	Y_4	width of mouth

Each face is constructed by using the four parameters in appropriate ranges. The shape of the face is a circle which is fixed in this example. The

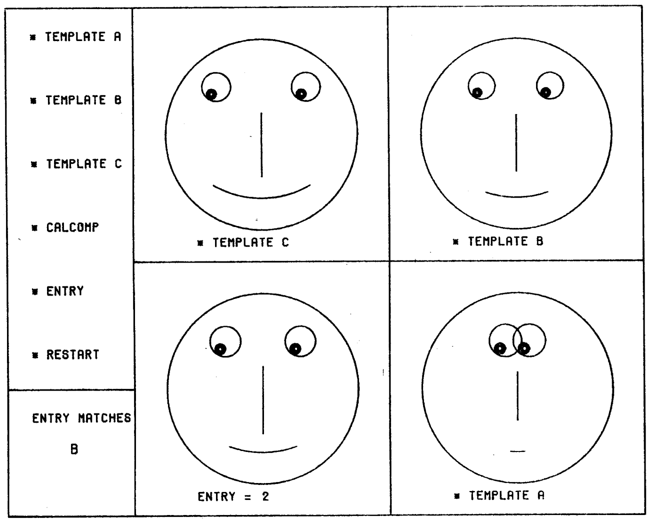

Figure 8 a. An Iris sample vector matched against Iris templates (mean vectors). Template A —Iris Setosa, Template B—Iris Versicolor, Template C—Iris Virginica

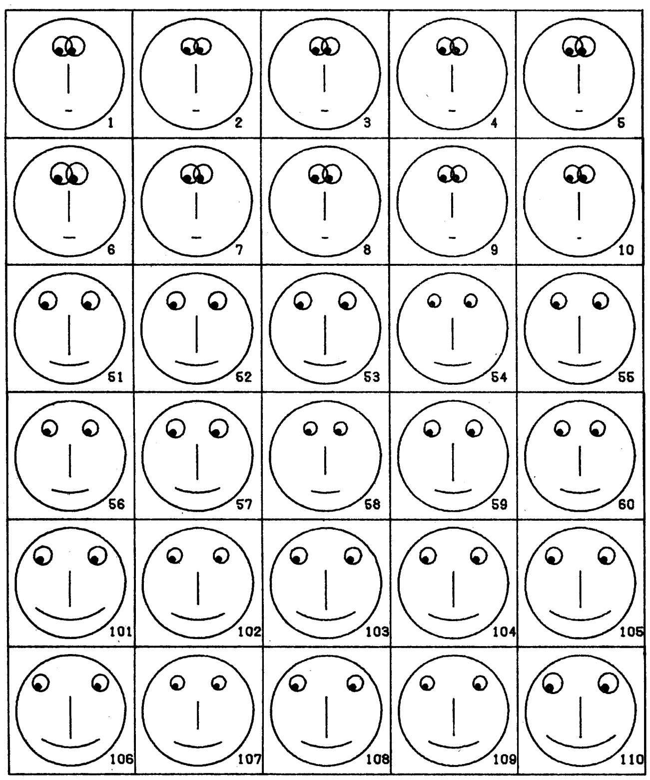

Figure 8 b. A sequence of cartoon faces corresponding to 30 Iris samples

Figure 8. Iris data displayed as cartoon faces

eyes are also circles symmetrically located with respect to the vertical line through the center of the circle. The nose is a vertical line segment and the mouth is an arc of a circle of constant radius. Figure 8a shows three faces corresponding to the three mean vectors of the three Iris groups and a fourth face corresponding to one of the Iris sample vectors being graphically compared with the mean vectors which may serve as templates for classification purposes.

Pictorial representations of this type appear to have at least two uses for interactive pattern recognition. First, they can be used for human-assisted classification of multivariable data. While a human's ability to classify a high-dimensional vector into one of several groups is rather limited, it is quite straightforward, at least psychologically, if the data is represented by faces (see Figure 8a). The second use is in the area of visually detecting changes or other major events in the data. When the faces are presented in sequence, the human may look at the sequence of faces and try to locate the instance where the faces change their character. It is true that such changes can be easily detected by a strictly numerical procedure. Unfortunately, these detected changes, without a visual mnemonic enhancement, may be distracted by other effects in the data. On the other hand, a major change in the faces can be easily observed, remembered, and recalled in terms of the appearance and emotions associated with the face. Figure 8b depicts a sequence of faces corresponding to a subset of the Iris data. The faces shown are the first ten samples from each of the three Iris groups. Note that the change of facial emotions from Group 1 (Iris Setosa) to Group 2 (Iris Versicolor) is clearly observable, whereas the change from Group 2 to Group 3 (Iris Virginica) is not, reflecting the inherent difficulty in differentiating these two groups of vectors.

Other methods of pictorial representation of data have been developed for interactive data analysis and classification. They may be found in the references listed in the bibliography.

Interactive Systems and Applications

In this section we will provide a brief survey of the interactive computer systems* developed to date for pattern recognition work. Two types of interactive systems exist. First, general-purpose systems have been developed which are primarily used as a design tool for pattern recognition research and development. These systems usually consist of a dedicated computer and one or more graphics consoles, designed for effective visual examination and other forms of human-machine interaction. The various display-oriented algorithms for data acquisition, analysis, and classification are usually provided by a collection of software modules. Underlying these modules is an executive program overseeing the entire operation. The main function of these systems is to help the system user develop

*Here we use the term "system" loosely to describe a computer program or a collection of programs implemented on a dedicated computing facility or simply resident on an existing computer.

better pattern recognition machines more quickly and more effectively than in the past. Versatility and flexibility are two of the primary design requirements for these systems.

The second type of interactive systems are for special applications in the pattern recognition area. Their main function is to provide a computing facility by which a particular pattern recognition problem can be best solved by expanding human's ability of decision-making with the assistance of computer graphics. These systems often require the active participation of a human in one or more of the three pattern recognition processes: data acquisition, pattern analysis, and pattern classification.

One useful characterization of any interactive system for pattern recognition is the type of inputs that the system is designed to handle. General-purpose systems are mostly suitable for numerically quantified multivariate data, regardless of the source of the data. For special systems, the particular form of the input data, be it a character image or acoustic waveform, becomes the integral part of system specification. The line between these two types of systems, however, is by no means clear cut and certainly need not be.

Given below is a list of some of the systems with a brief description for each. The systems listed cover the following areas of application: 1) general systems, 2) data analysis, 3) signal and waveform processing, 4) image analysis, 5) character recognition, and 6) biomedical applications.

General-Purpose Systems

PROMENDE—A *P*attern *R*ecognition *O*nline by *Men* and *D*igital Computing *E*quipment. This is the pioneer work of interactive systems for general pattern recognition work. Designed at Stanford Research Institute as an aid for interactive data analysis, PROMENDE is supported by three major software modules: data manipulation, graphical plots, and numeric algorithms. It is also one of the early research efforts aimed at exploring, implementing, and evaluating the feasibility and usefulness of interactive computer graphics for the design of pattern recognition systems. An extremely rich set of display-oriented algorithms, including the ones discussed above, has been studied and evaluated in conjunction with various pattern recognition applications. References for detailed information may be found in Ball and Hall.[21]

SARF—A *S*ignature *A*nalysis *R*esearch *F*acility. As in the case of PROMENDE, SARF is implemented on a dedicated computer system with its software facility organized into various modules allowing efficient human-machine interaction. A particular subsystem in SARF allows the human to modify the characteristics of the transducer, thus controlling and modifying the data acquisition process of a pattern recognition task. The system was developed by the General Motors Corporation. Additional information on SARF and its applications may be found in Stanley et al.[22]

OLPARS—*O*n*L*ine *P*attern *A*nalysis and *R*ecognition *S*ystem. This is perhaps the largest and most widely used interactive facility developed to date for the solution of both pattern analysis and classification problems. Developed by the Rome Air Development Center, OLPARS is currently resident on two computer systems: one on the PDP-11/45 computer coupled with the Vector General graphics terminal, and the other on the HIS-6180 computer under the Multics timesharing system. OLPARS is supported by a variety of software routines, including the display-oriented algorithms described in the previous section, thus providing a truly interactive environment for pattern recognition work. Sammon[23,24] gives additional information on this system.

Data Analysis

STATPAC—A Lightpen Controlled *Stat*istical *Pac*kage for Online Data Analysis. The core of this system is a collection of display-oriented operations the user may choose from to perform the data analysis function. The system was developed by Goodenough.[25]

Factor Analysis. This is a graphics-based system that enables the human to solve factor analysis problems in a sequence of steps. User interaction is required whenever a decision concerning analysis should be made at each step. See Weinstein and Frane.[26]

Data Fitting. Developed at the Stanford Linear Accelerator Center, the system is designed to aid the user in solving least-square data fitting and related problems involving functional minimization. A novel feature of the system is a display-oriented interactive function minimizer which aids the user in locating and comparing different local minima. See Smith.[27]

Graphical Analysis and Discrimination. This is perhaps the most widely used data analysis system that includes interactive facilities. The system is based on a library of statistical program such as the BMD series developed at UCLA. It provides the user with a variety of data screening, analysis of variance, and classification programs. User interaction with the system is through the extensive use of a display scope and lightpen and keyboard facilities. See Dixon.[28]

Signal and Waveform Processing

DX-1—The Experimental Dynamic Processor. This is an online display-oriented computer system designed as an aid for the investigation of data compression and transmission as well as general pattern recognition problems. Developed at USAF Cambridge Research Lab, it is one of the few systems in which color display plays an important role in user's interaction with the computer. Additional information may be found in Walter.[31,32]

WPS—A *W*aveform *P*rocessing *S*ystem. This is an interactive system designed to aid the user in extracting features from waveform data for subsequent analysis and classification purposes. A detailed account of WPS and its relation to OLPARS can be found in Foley.[33]

IPS—This *I*nteractive *S*ignal *P*rocessing System, developed by Control Data Corporation, allows the user to have control over a variety of routines involving one or two-dimensional waveforms. A unique feature of the system is a learning program that provides the user with different levels of interaction with the computer. Details of this system can be found in Freeman.[34]

Image Analysis and Interpretation

GLOPR—*Go*lay *L*ogic *Pr*ocessor. This is an interactive system for image processing developed by the Perkin-Elmer Corporation. Named after its inventor, M. Golay, the system is designed to speed up feature extraction from binary images performing a set of special (Golay) transforms. The human-machine interaction is achieved through an interactive programming system which provides an extensive set of commands allowing the human to design and test image analysis algorithms. A discussion of this system can be found in Preston and Norgren.[35]

ISIS—An *I*nteractive *S*cene *I*nterpretation *S*ystem. Developed at the Stanford Research Institute, the system is designed to allow the user to describe basic perceptual concepts to a computer in terms of pictorial examples. Through this human-machine interaction, a computer can be "taught" to understand and interpret a class of pictorial scenes. A description of this system can be found in Tenenbaum, et al.[36]

Human-Face Identification. This system, developed at Bell Laboratories, is programmed to determine the identity of a human face described by a subject who is inspecting a photograph. A description of this system can be found in Harmon.[37]

ISIR—An *I*nteractive *S*ystem for *I*mage *R*econstruction. This is a system designed to explore the human mind in determining the "best" methods for the reconstruction of images from their projections. A description of this system is given by Shliferstein and Chien.[38]

Character Recognition

Interactive Text Reading. This system, developed at IBM, reads unformatted printed text. Through a display and a graphical tablet, user interaction is provided at different stages of the pattern recognition process. This includes user's selection of areas of text to be processed (data acquisition), user's supply of parameters for the analysis of character templates (pattern analysis), and a post-editing process allowing the classification logic to be reviewed and modified (pattern classification).

Online Error Correction. In the past few years, a number of commercially developed character recognition systems have been equipped with one or more interactive features. One such feature is the capability of online error correction. This allows the user to intervene whenever a character fails to meet the recognition criteria. Unrecognized characters are displayed and the user is allowed to key in the correct character identities before the system resumes the automatic recognition process. Figure 9 shows a typical optical character recognition system with online error correction facilities. DATAPRO[42] provides a list of commercially available OCR systems with online correction capabilities.

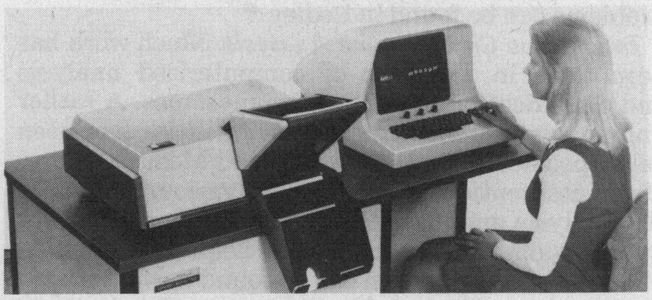

Figure 9 a. System configuration showing components for human-machine interaction

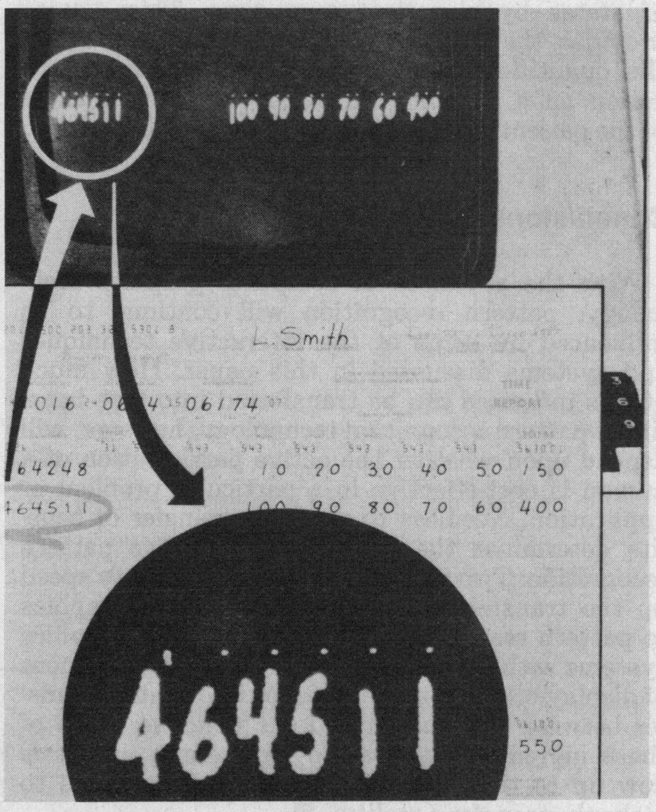

Figure 9 b. The complete line containing an unacceptable character (numeral four with closed top) is displayed with three dots positioned over the character to be corrected. The operator then identifies and keys the proper character.

Figure 9. Cognitronics Corporation's System/70 Character Recognition System with interactive error-correction features (courtesy of Cognitronics Corporation, New York, N. Y.).

Biomedical Applications

MACDAC. This is an interactive system designed for *Ma*n Machine *C*ommunication with *D*igital *A*utomatic *C*omputer with primary applications in the biomedical area. Developed by the National Biomedical Research Foundation, MACDAC has extensive user-controlled analysis and display facilities. The pattern recognition aspects of this system as applied to clinical and health care delivery problems can be found in Ledley.[45]

Interactive Chromosome Analysis. Much work has been done in the area of computerized analysis and classification of human chromosomes. A rather unique system with interactive facilities has been developed at the Tufts New England Medical Center. User intervention is provided at various stages of the analysis and classification process or whenever human judgement is considered helpful. A detailed discussion of the system can be found in Neurath.[44]

Interactive Clinical Interpretation. This system, developed by IBM and the Albert Einstein College of Medicine, permits the use and interpretation of multivariate data analysis methods in the assessment of the critically ill. A unique interactive feature of the system is the display of transitions of states by a patient over time. This display provides the necessary, dynamic information for the quantification and application of therapeutic action on a patient, thus improving the chances of the patient's recovery. See Goldwyn et al.[43]

Conclusions

With the advances of computer graphics technology, pattern recognition will continue to be influenced by some of the interactive techniques and systems discussed in this paper. How much of this influence can be transferred into true benefits of pattern recognition technology, however, will depend upon whether the active participation of a human is cost-effective in a particular problem or application. Needless to say, this transfer of benefits determines the future of interactive pattern recognition. Two ingredients are necessary to speed up the transfer of benefits of computer graphics to pattern recognition: the availability of graphics systems with decreasing costs and the development of display-oriented techniques for information transfer between the human and the machine. Both of these ingredients appear to be present, and it is now up to the pattern recognition enthusiasts to make the transfer a reality. ■

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The entries listed below are grouped into various categories for easy reference by the reader. They are not meant to exhaustively circumscribe each area, but are provided to indicate particular known sources of information or references cited in this article. Additional bibliographical information may be found in Kanal,[1] Terekhina,[2] and Chien.[4]

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