Image Processing and Computer Graphics in the Human Sciences

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INTRODUCTION

Since computers began to play an important role in everyday life, the style of data processing has changed greatly. At first computers were used in business and scientific applications where processing of coded and/or numerical data was the main concern. Usually, in these applications, information to be fed into a computer system is digitized and coded beforehand, and the procedure for obtaining results from this input is almost formularized. The computer was expected to deal with vast amounts of data and to calculate very fast.

Computer data processing was gradually expanded to various non-technical peripheral fields, not excepting the human sciences [LUSIGNAN and NORTH 1977; PATTON and HOLOIEN 1981; BAILEY 1982]. The principal characteristic of information processing here, especially in studies like ethnology, is the significance of pattern information processing.

The term *pattern* is used in various situations and may have a different meaning and concept in each context. Even restricted to the field of computer information processing, pattern information has by no means an exact definition. Two-dimensional visual artifacts such as images and figures, are what we usually associate with patterns, but one-dimensional signals, such as sound and some specific wave forms, also exhibit patterns. More abstract are patterns of culture or behavior, but in this article the term pattern refers mainly to visual and one-dimensional signals.

Developing a pattern-recognition system has been very difficult because the mechanisms by which human beings recognize patterns are not well known. Despite substantial basic and theoretical research, practical results could not be obtained for a long time.

In the 70s, noteworthy progress in pattern information processing was brought about by the space project. Successes in this field have spread to every engineering and scientific field, and many attempts have been made to replace or aid human information processing by computer. Research results obtained in engineering fields have supported efforts to apply these techniques to some non-technical fields, such as the human sciences and medical science, where many kinds of pattern information, *e.g.*, photographs, sketches, maps and wave forms, have to be handled.

In the medical field remarkable progress in pattern information processing has been due to a grounding in general computer data processing and the big investment in this area of research. In the human sciences, on the other hand, progress in applying pattern information processing has been rather slow. Although no remarkable results have yet been obtained, this kind of processing technique should be a powerful tool in the human sciences research of the future.

This paper focuses on some visual pattern information, *i.e.*, images or pictures, and surveys applications of visual pattern information processing in human sciences research. Although all the examples and references introduced are not necessarily related directly to the human sciences, a number of them have possibilities for application there.

After discussing the relationship between pattern information processing and the human sciences, some technical concepts and methodologies in visual pattern information processing, (that is, image processing and computer graphics) are reviewed, and the scope of this survey is made clear. Finally, actual application of image processing and computer graphics is surveyed. Most of the research presented here is made at the National Museum of Ethnology, Japan, but notable research at other institutions is also described.

PATTERN INFORMATION PROCESSING IN THE HUMAN SCIENCES

In the field of documentation, materials have been classified into three categories of information [STIBIC 1980]. The *primary information* refers to original documents such as books, articles and reports, and the *secondary information*, to documents used for referring to the primary information, such as abstracting journals, bibliographies and indexes. The *tertiary information*, relatively new compared with the other types, denotes a kind of directory or list of secondary informations, for example, a bibliography of bibliographies, or an index of on-line databases.

Into this taxonomy we will introduce a new category of information named *raw information*. Whereas primary information denotes written documents, raw information is the kind of data gathered in the course of research. Examples are pictures, photographs, sketches, rough memoranda and observation data. In other words, whereas primary information is coded, raw information is non-coded.

This raw information plays quite an important role in several human sciences with characteristics of a field science, such as ethnology, archaeology and geography. Researchers gather much data in their field work, and arrange it into primary documents. Data will be selected during an investigation, but the resulting documents or articles must always be supported by the raw information, from which things start in field sciences.

Since all disciplines in the human sciences do not have the characteristics of field science, raw information does not necessarily dominate in the human sciences research in general. Since, however, the methodologies and the subjects of processing of coded information have become definite to a certain extent, the problems to be solved are rather in the treatment of the non-coded raw information. In this sense it may be said that the processing of raw information will characterize information processing in the human sciences of the future.

The reason why so far there have been only few discussions concerning the processing of the non-coded raw information in the human sciences might be that the actual level of the technology did not necessarily follow the researcher's ideas and needs.

In 1965 Gardin attempted to classify computer uses in anthropology [GARDIN 1965] and introduced a two-dimensional table, which classified computer uses according to the types of data to be processed and the types of operation which might take place. In terms of the types of data he set up two categories: *symbolic* and *physical*, and symbolic data are further divided into two sub-categories: *natural languages* and *special codes*. Physical data in this context may be considered to correlate closely with what we call raw information. Various examples of computer uses, from very simple to highly complex, are classified according to this table. As for physical data, however, table entries are left blank. Actually, Gardin stated in the text that studies in pattern recognition might be placed there, but it might be difficult to list all the possibilities at that time. Today we are able to discuss these topics in more detail because of the significant progress in information technology.

Most of the raw information is pattern information: images, figures, sounds and wave forms. These have been so far dealt with subjectively rather than objectively, relying on human pattern recognition ability. Development of computer technology and continuing research on pattern information processing have, however, made possible the objective processing of patterns.

Hence, the principal feature of future information processing in the human sciences may be the significance of pattern information processing [SUGITA and HACHIMURA 1981].

PROCESSING TECHNOLOGIES OF VISUAL PATTERN INFORMATION

Visual, *i.e.*, pictorial, is the most typical among general patterns and it is usual that the simple word *pattern* implies *visual pattern*. In fact, from its earliest beginnings, research on pattern recognition has dealt, to a substantial extent, with visual patterns. This chapter therefore describes the concept and methodologies of visual pattern processing in order to clarify the scope of this survey, and also to give some definitions of terms.

Image Processing and Computer Graphics

Processing of visual patterns by computer takes different forms in a variety of applications. It has been usual, in computer science, to classify such operations into two categories; *image processing* and *computer graphics*.

Image processing refers to two types of operations: those that transform images into other images, and those that map given images into non-images, *i.e.*, numerical or symbolic descriptions. The term image processing is sometimes used only for the first type of operation, *i.e.*, for image-to-image transformations, and in this case, the second type, image-to-non-image mapping, is called pattern recognition. In this paper, however, we shall adopt the former loose definition.

Related terms for image processing are picture processing, image analysis and pictorial data processing. Very little difference in meaning separates these terms and generally they appear in the same context.

Different from image processing is computer graphics, which deals primarily with the computer generation and manipulation of images that are specified by some kind of non-image descriptions.

It could be said that image processing is a technique to analyze pattern information but computer graphics synthesizes it. In the following sections methodologies and some specific topics of both disciplines will be described in some detail.

Methodologies of Image Processing

The principal technical operations in image processing include:

(a) transformation
(b) measurement
(c) classification.

Transformation, an operation to convert an input image to an other image, is further classified into two categories: image restoration and image enhancement, both sometimes called *filtering*. The first restores images corrupted by some degradation process, while the second converts images in order to emphasize some specific features they contain. Exact classification of each image-to-image transformation into the above two categories may be difficult, but this discrimination is very common in image processing.

Examples of image transformation include:

(a) removing *noise*, such as speckles and stripes;
(b) sharpening images blurred by poor focus or motion;
(c) correcting distortion; and
(d) increasing contrast of images.

If the cause of image degradation is known in advance, the method to improve images corrupted by this process may be determined. The process of degradation is, however, usually not known exactly, or it would be strongly probabilistic in nature. It is usually difficult, therefore, to fully restore the quality of images, and, in practice, some approximations are introduced into the underlying degradation process, or trial-and-error strategies are employed.

Image restoration and enhancement techniques have demonstrated their power in space observations by interplanetary satellites like Voyager. Images of Jupiter and its satellites, transmitted by very weak radio signal and corrupted by various kinds of noise, could not be seen as clear pictures without these digital image-processing techniques.

The second category of image processing is measurement, a kind of operation to extract some numerical feature values from given images. Measuring sizes of objects and counting the number of objects contained in an image are examples of measurement operation.

Common in measurement operation is the extraction of *features*. For instance, when counting the number of particle objects included in a picture, the most basic task is to separate object particles from a background and other irrelevant objects. Key or feature information to discriminate relevant and irrelevant objects might be a change in brightness or a change in texture and color, but there is no universal feature value to discriminate them. It is usually difficult to establish what information is relevant for current measurement.

The third category of image processing classifies objects into several classes according to their feature values. This kind of operation can, therefore, be characterized as a mapping from image to symbolic descriptions which indicate classes. This classification requires measurement because it uses some feature values of the objects.

Recognition of printed characters is a typical application of image classification. After each character yields some feature values, it is classified by appropriate decision-theoretic methods.

All of the image-processing operations are not necessarily classified exclusively into three categories, but most of the image processing operations are combinations of these three types. The most sophisticated application of image-processing techniques is pictorial pattern recognition. Automatic diagnosis of medical X-ray pictures is an example of pattern recognition.

The typical and basic procedural configuration of pictorial pattern recognition is illustrated in Fig. 1. Object images are first digitized and then pre-processed. This pre-processing step does some preliminary processing for recognition, applying image-to-image transformation. Removing noise and correcting distortions are typical pre-processing operations.

Feature extraction produces relevant information for subsequent discrimination. Although original image data have vast amounts of information, very little may be significant for pattern discrimination. Thus feature extraction is regarded as an information-reduction process. Input for this step is in the form of images and output is a set of numerical values. Feature extraction in a pattern recognition system is, therefore, a processing of image measurement.

The final discrimination step in a pattern-recognition system is a mapping from extracted feature values to some symbolic descriptions which represent classes to which each of the object pattern belongs. In this step some theoretical approaches are possible: a number of pattern-discrimination theories have been established, such

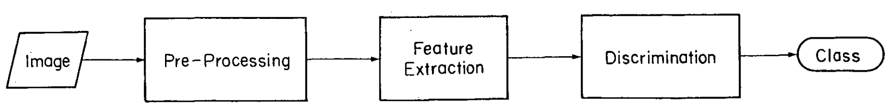


Figure 1. Typical Procedure of Pattern Recognition

as supervised and unsupervised classifications.

Methodologies of Computer Graphics

As we have seen before, the principal characteristic of computer graphics is that it generates images from non-images, *i. e.*, from numeric or symbolic descriptions.

The principal research topics in computer graphics include:

(a) data structure
(b) modeling
(c) image generation.

Very brief descriptions of each topic are presented below.

The first heading, research on data structure, is related to problems of efficient graphic data storage. The amount of storage needed, the speed of accessing graphic data, and the speed of generating corresponding images depend on the data structure, *i.e.*, the organization of the graphic data stored in the computer system.

Images generated by computer graphics techniques simulate scenes of the actual world. The computer system, therefore, has to model the real entity. Problems of modeling real entities relate to the second heading.

Actual methodologies of generating visible images, sometimes very realistic and sometimes abstracted, constitute the third problem of computer graphics. At the early stage of the development, most of the computer-generated images were simple line drawings, but after rapid progress in hardware technologies and the development in algorithms, computers are now able to generate very realistic images and scenes.

APPLICATIONS OF IMAGE PROCESSING TO THE HUMAN SCIENCES

Image Transformation

As described above, the principal techniques in image transformation are restoration and enhancement, and these techniques are usually employed as pre-processing for other processing, such as measurement or classification. Topics in image transformation are, therefore, seldom referred to separately, but these techniques are actually used in various image-processing research activities.

The chief objective in image restoration and enhancement is to improve the original image. Hence, it is quite natural to incorporate these techniques into archaeology, where images are often obtained under badly restricted conditions, such as very low illumination, or where some of the specific features are covered with irrelevant information. One example of such an application is found in [SCOLLAR 1977]; enhancement techniques applied to aerial photographs have made an image of archaeological remains clear.

Noise-removing restoration (filtering) techniques can be applied to every application area. In the human sciences research, a noise-removing filter can restore antique photographs corrupted by stain and smear. In [TAMBURELLI 1981], some digital image processing was attempted to reduce noise in the reputed image of the

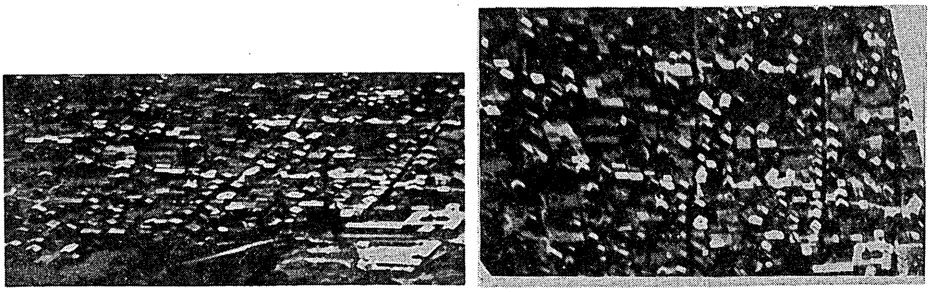
Holy Shroud of Turin, and consequently to make the image of Christ definite.

Blur caused by poor focus or camera motion is likely to occur in photographs taken during field work. Restoration techniques to deblur such corrupted images may therefore be helpful to fieldworkers. As described above, blur caused by a process with unknown or highly complex characteristics cannot be rectified completely, but even in these cases some interactive heuristic approaches are possible.

Another image-transformation technique which may be useful, especially for field work, is geometric correction, which was originally used to compensate geometric distortions caused by incomplete optics or defects in the imaging system. These techniques can convert some specific projection to another. For example, a bird's-eye view of a village photographed from the top of a mountain is in a perspective projection. It can be converted to an approximately orthographic projection, which can be used for drawing orthographic maps of the village. For this, the actual locations of several reference ground points and their correspondence to the image must be known in advance. An example of this transformation is shown in Fig. 2. A similar application is also found in [PALMER 1977].

Image-restoration and enhancement techniques can be applied to the conservation and restoration of archaeological and ethnological objects. In conservation technology various methods of non-destructive inspection have been used. X-ray imaging and ultraviolet imaging are typical. Since images obtained by these techniques are usually of poor quality, image restoration and enhancement may be very useful to improve them.

Somewhat different in nature from what has been described so far is an application of X-ray computer tomography to the conservation technology, especially to the inspection of precious ancient objects. Although it was originally a technique to reconstruct trans-axial cross-sectional images of the human body from projection data obtained by X-ray based on the difference in X-ray absorption coefficients of materials, it may also be applied to non-human objects. The first apparatus for clinical applications emerged commercially in early 70s, and this kind of machine is commonly used at principal hospitals all over the world. The apparatus is very expensive, but it provides very valuable data about the interior structure of objects.



(a) Original (b) Transformed

Figure 2. Image Transformation from Perspective to Orthogonal Projection

This X-ray computer tomography, applied to a sculpture of the Buddha [MIURA *et al.* 1980], revealed not only its structure but also a miniature Buddha and several pieces of paper inside the main body. The same technique was able to generate cross-sectional images of a live tree for the measurement of its annual rings [ONOE *et al.* 1983]. In societies that do not maintain historically accurate records of rainfall or harvests, such data may be the only means for establishing a reliable chronology of significant events. Of major importance is the ability to observe interior structures clearly without damage to the objects.

Measurement

The second topic in image processing is measurement: *e.g.*, establishing an object's dimensions and counting the number of objects.

Once several feature points are located in an image, it is not difficult to calculate distances between them, and hence, to measure their geometry. Although distances measured on the image are in relative units, they can be calibrated to actual units by specifying the geometric relationship between the imaging system and the object.

The difficulty lies in locating relevant feature points in the image. Often computers cannot detect features which are easily discernible to human observers, who can employ all empirical knowledge, while computer algorithms usually rely only upon information contained in the image itself. Therefore, a universal algorithm for locating feature points, which can be applied to various kinds of images, does not exist, and it is quite difficult to detect less definite features in images.

Under limited conditions where the kind of objects and a format of images are to a certain extent controlled and fixed, we may automatically extract some specific feature points to be used for the measurement. Outlines of objects may be extracted, for example, when they are placed before a definite background of uniform brightness and color. Once the definite outline of the object is extracted by detecting differences in brightness or color between object and the background, feature points such as corners and extremities may be located on the outline, and these can be used to measure the dimensions of the object.

Although rather simple and limited, this image-based measurement technique may be very helpful for dealing with a large number of objects. A system for measuring ethnological artifacts by this technique has been developed in the National Museum of Ethnology. (The overall configuration of the system is illustrated in Fig. 3.) Objects are placed on a turntable, and images are obtained by three high-precision electronic cameras placed above, before and halfway-above. From the above and front positions cameras obtain quasi-orthographic views: the camera in front gets two views by rotating the turntable by 90 degrees. Unlike the others, the camera placed in oblique position is a color camera, and produces a bird's-eye view of the object. The image obtained by this camera is not used for measurement, but produces an aesthetic photograph.

Three quasi-orthographic images are used to measure the maximum dimensions in height, width and depth of the object by extracting its outline. Since the geo-

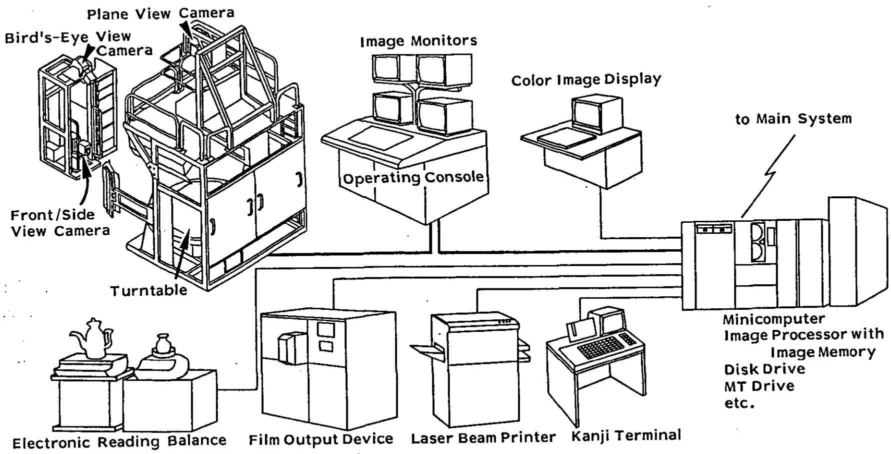


Figure 3. Image Input and Automatic Measuring System for Artifacts

metric relations between the turntable and the cameras are known as well as the optical characteristics, the actual dimensions of the object are obtainable from dimensions measured on it.

Of course, this set of three images does not constitute true orthographic views, since the images obtained by the ordinary optical system are in central (perspective) projection rather than in orthographic (parallel) projection. Therefore, the dimensions measured by the system may contain a certain errors, which may vary according to the shape and size of the material. This degree of error is tolerable when only rough dimensions of the material are necessary. Museums have stored and are storing a large number of objects, and it is very time-consuming and laborious to measure them precisely one by one. From the standpoint of material management, it may be more desirable to obtain a large collection of data (even somewhat rough) in this non-contact fashion rather than a small number of precise data.

Fig. 4 shows the result of measurement obtained by the system described above, *i.e.*, figures of height, width and depth superimposed on the original images. This kind of measurement is standard, but optional measurements about distance between arbitrary points are also possible through an interactive operation via display screen. The four images obtained are printed by a laser beam printer and arranged in card format together with results of measurement and some ancillary descriptive information.

Not merely an automatic measuring system, the system operates as an image-data-capturing machine for an image database of museum materials. (This aspect will be discussed below.)

Pattern Classification and Recognition

One of the most remarkable and attractive application areas of image processing might be automatic classification or recognition of object patterns.

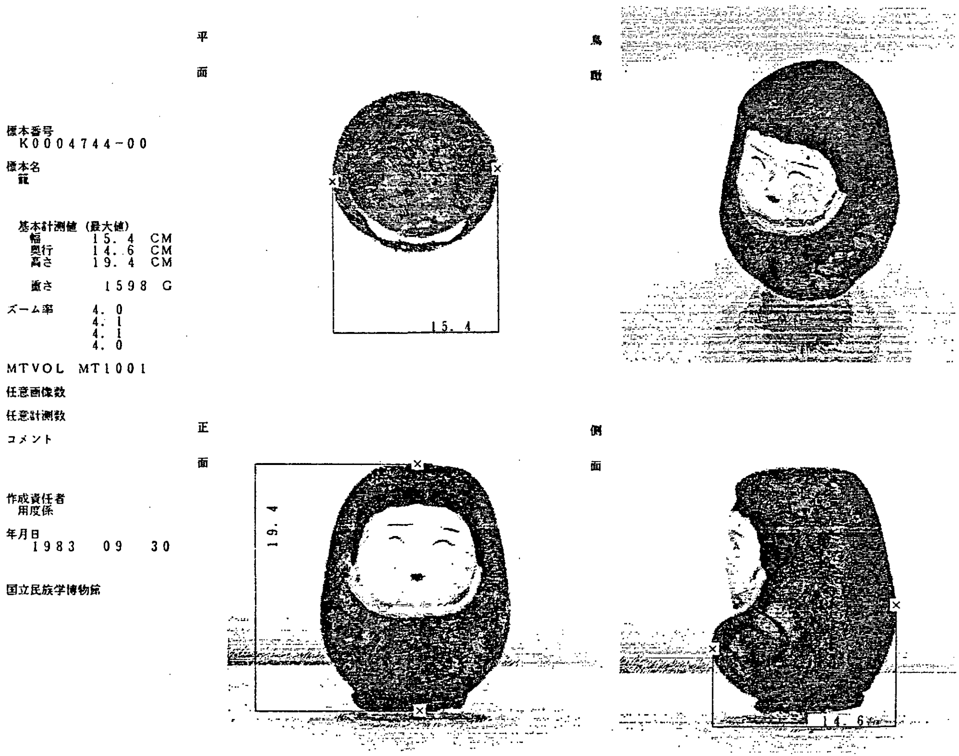


Figure 4. Result of Automatic Measurement

As described above, the fundamental procedure of pattern recognition is a three-step sequential application of pre-processing, feature extraction and discrimination. Meaningful results by this straightforward procedure are, however, quite rare, and other strategies employing feedback and/or man-machine interaction are usually required. Difficulties usually arise (as was previously mentioned) in the feature extraction step. In the human sciences seldom can a collection of well-defined images be obtained under fixed conditions. Extraction of meaningful features being therefore very difficult, few results have been reported.

We may find several research projects concerned with the classification of visual patterns, such as those drawn on ancient objects, but quite likely they use no image-processing techniques at all, that is, feature extraction from the original images is made by humans, mostly very experienced professionals [GURALNICK 1976].

Pattern classification may work, to a certain extent, in the applications where key information regarding an object's patterns is contained mostly in its outlines or other curvilinear features, and objects to be classified are principally two-dimensional, *i.e.*, planar, rather than three-dimensional.

Recognition of written characters is one example. Typed or hand-printed Roman characters have been intensively investigated, and for typed text fairly good results have been obtained and several systems are now commercially available.

Character recognition technology is, originally, not directed toward the needs of the human sciences, but it will create powerful tools for researchers in the fields like linguistics and ethnology, in which large quantities of text data must be dealt with. The same kind of character recognition technique for character systems other than the Roman alphabet, such as Chinese, Japanese, Han-geul and Thai, has been investigated. Recognition of hand-printed letters is much more difficult, but continuing research has used information about not only structure but also strokes and pen movements.

An example of classification of planar patterns is found in the automatic typology of arrowheads. Information concerning the shape of an arrowhead is well conveyed by its outline in planar view. Outlines are extracted from input images, and then specific feature values, called Fourier descriptors, are extracted from each closed curve. The value of the Fourier descriptors constitute a feature vector of the pattern, and a set of feature vectors obtained from a set of arrowhead patterns is then fed into a clustering procedure, which uses the hierarchical clustering algorithm.

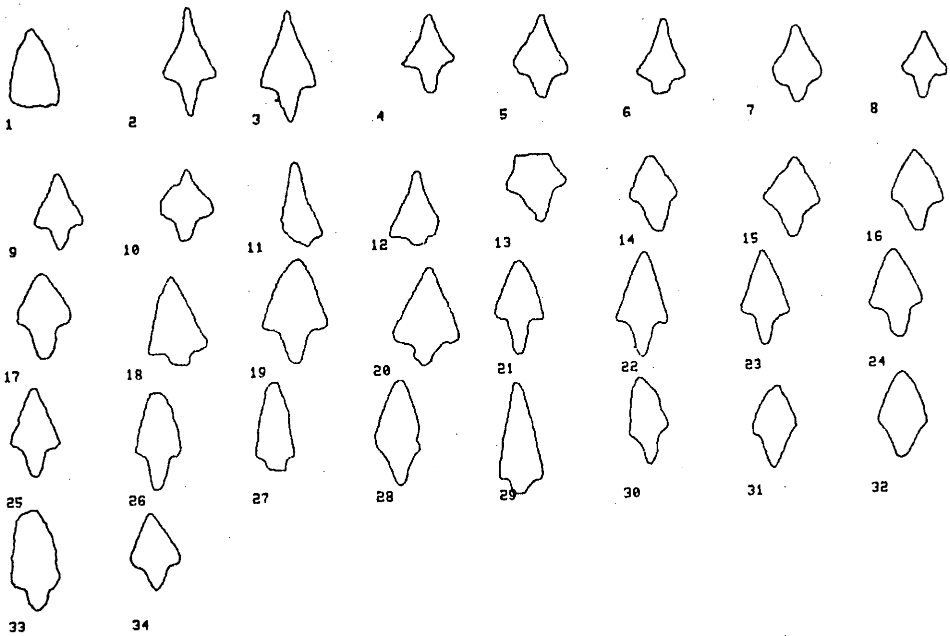
Fig. 5 shows one of the processing results, with the outlines extracted from the original image shown in Fig. 5(a). An automatically generated clustering result is represented on the dendrogram in Fig. 5(b). Outlines of sample arrowheads are depicted on the top row in the figure. The measure of the difference in the pattern is, in this case, the Euclidean distance between feature vectors, and the downward direction in Fig. 5(b) corresponds to an increase of distance. Here the dendrogram shows this set of arrowheads to be roughly divided into three groups which are apparently different in shape.

Typology of artifacts is also found in [Bietti and Zanello 1980]. Attempts were made to classify keyhole-shaped tombs by their three-dimensional shapes [Ozawa 1978]. Another example of pattern recognition which may be applied to research in the human sciences is automatic recognition of music notation [Perau 1971; Perau 1975], automatic seal identification [Fan and Tsai 1984] and identification of human facial profiles [Harmon *et al.* 1981].

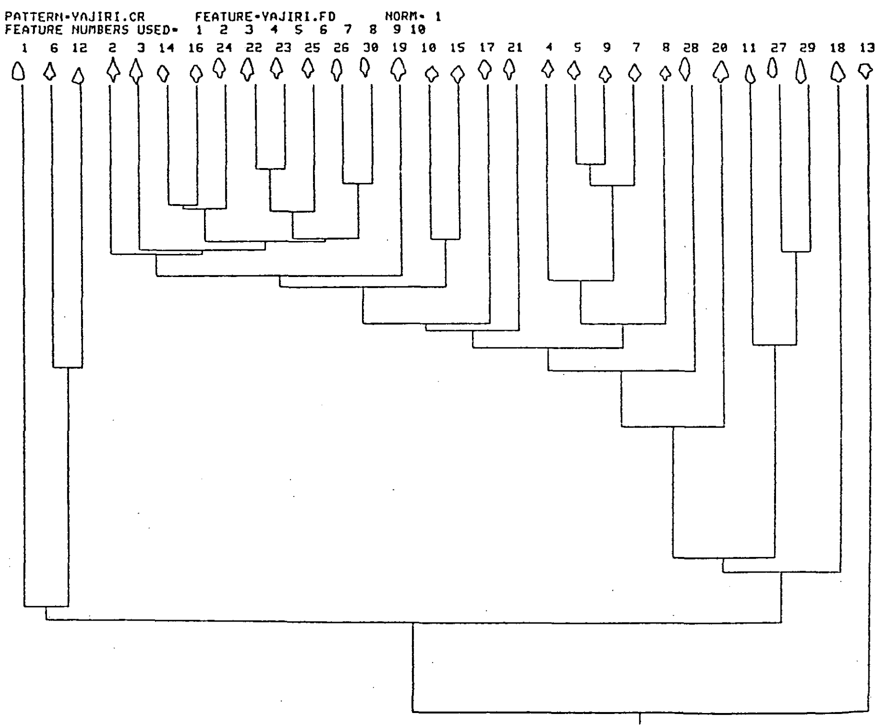
Processing of Remotely Sensed Images

Remote sensing is a technique for acquiring physical information about the earth's surface from some distance away, as from an aircraft or satellite. Originally developed for earth-resource survey projects, it has been used recently in various other applications. Presently satellites named Landsat have been capturing images of the earth's surface by means of a special image sensor, a multi-spectral scanner. This satellite orbits the earth once every 103 minutes, and it scans the same area on the surface once every 18 days. For each scene, the coverage is 185 km by 185 km. Data captured by this satellite, distributed from official institutions at reasonable cost, have been widely used in various research and business applications.

Because Landsat image data are multi-spectral, *i.e.*, composed of multi-band images, and are originally acquired in digital form, they are suited for quantitative and objective computer analysis. In processing Landsat images, every kind of



(a) Outline patterns of arrowhead



(b) Result of clustering

Figure 5. Clustering of Arrowhead Patterns

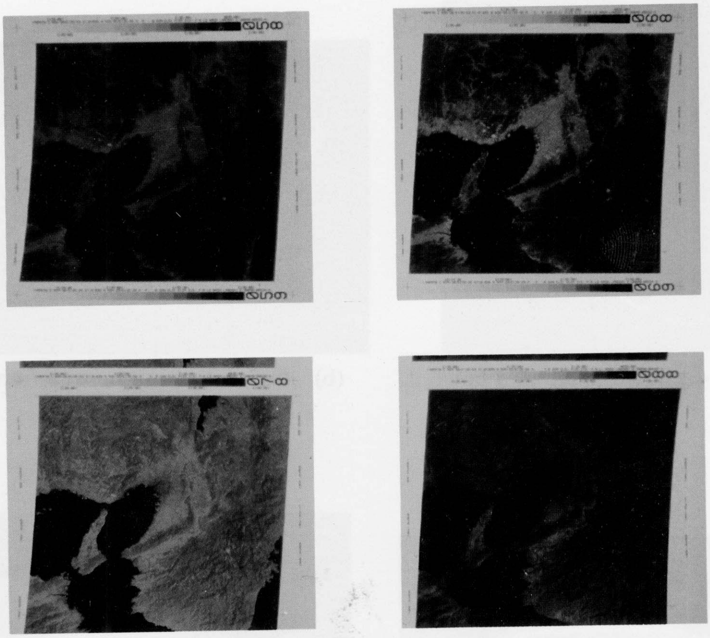
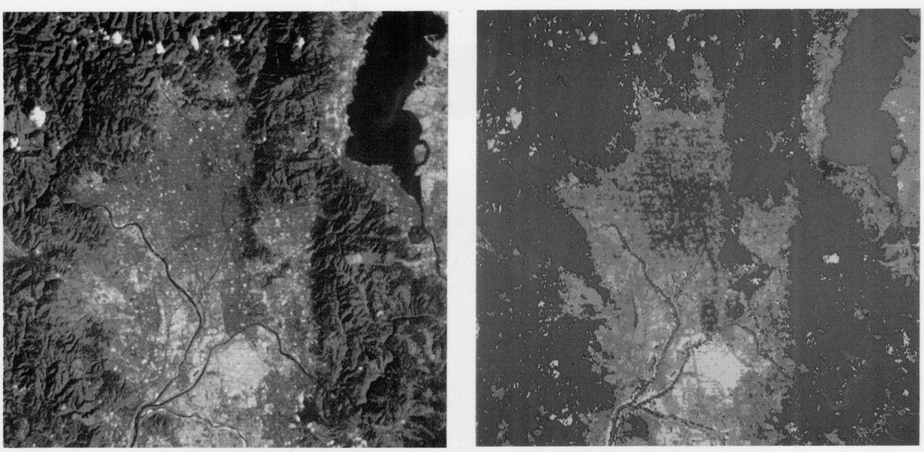
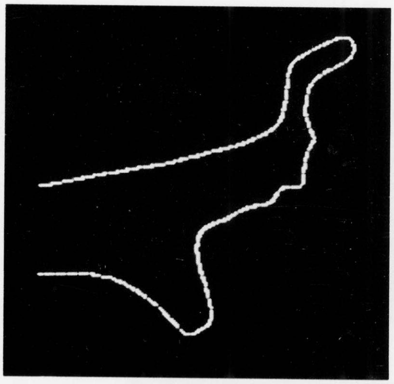


Figure 6. Landsat Multi-Spectral Images

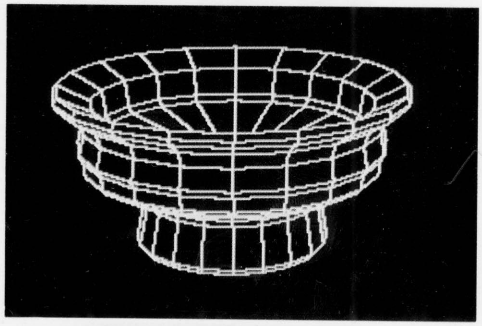


(a) Color composite image (b) Result of land use classification

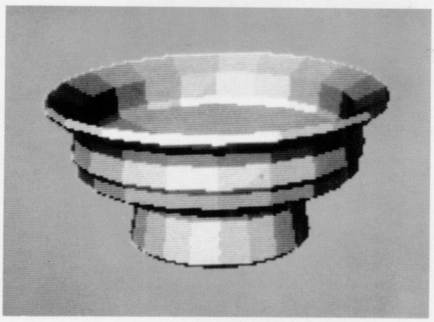
Figure 7. Landsat Image Processing



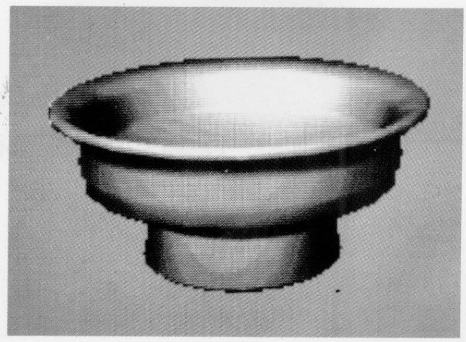
(a) Cross-sectional figure of a bowl



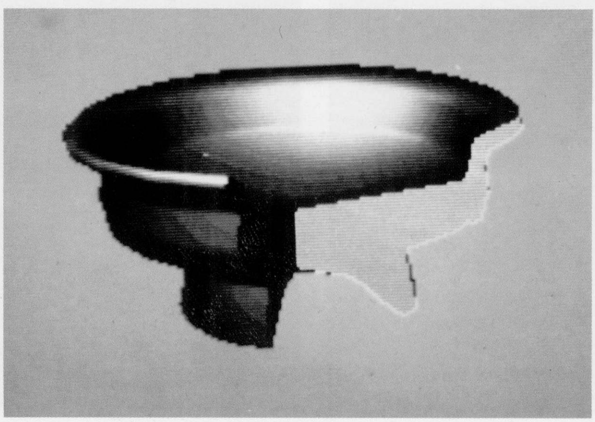
(b) Reconstruction by wire-frame model



(c) Surface shading



(d) Smoothed surface shading



(e) Cut-model display

Figure 8. Shaded Graphics

image-processing technique may be applied: transformation, measurement and classification [LANDGREBE 1981].

By analyzing Landsat multi-spectral images, we can obtain information about spatial distribution of land use and vegetation etc. Moreover, since Landsat repeatedly acquires information about the earth's surface, temporal changes can be followed. Some geographers and ethnologists therefore pay much attention to these data in their research.

Of the several articles concerning the application of Landsat data in the human sciences [ALLAN *et al.* 1979; CONANT 1978], only a few have been concerned with computerized analysis of images. One of the principal reasons for this lack of computerized analysis might be that a Landsat image needs various kinds of ancillary information in order to produce significant results, and it is usually difficult to incorporate this information into the analysis system.

Fig. 6 shows Landsat images of four spectral bands, covering the Kansai district of Japan. Fig. 7 shows examples of basic processing on a Landsat image: Fig. 7(a) is a color composite image obtained by digital processing from four spectral images, in which difference in land cover appears as difference in color. The result of applying a supervised classification procedure to this sample of multi-spectral images is shown in Fig. 7(b), which presents a colored land-use map of urban and suburban areas of Kyoto city.

Examples of practical Landsat image processing are found in [MISRA and WHEELER 1978; WHEELER and MISRA 1980], where Landsat data are used to classify crops covering the object area. A system for processing Landsat data which makes use of such geographical information as maps and census data as ancillary information was proposed in [ZOBRIST and NAGY 1981].

Image Databases

An image database is a system to store images and facilitate their efficient retrieval. As databases and database management systems for coded data have been developed in various areas, they might be said to have matured from both the technical and applications viewpoints. The next goal, therefore, is to develop databases for non-coded pattern data, *e.g.*, image data and sound data.

For several years intensive efforts have been directed to the development of image databases [TAMURA and YOKOYA 1984]. Many of these were concerned with some specific application, such as clinical medicine and remote sensing. Few were concerned with direct application to the human sciences. Since, however, as stated above, pattern data, especially image data, play a very important role in human sciences research, and researchers have to deal with both a large variety and vast amounts of image data, image databases of this type might be very useful for human sciences research.

Generally speaking, strategies for retrieving image data are twofold. One is a natural conceptual extension of the conventional code database. Secondary information related to image data (for example, annotation data and the symbolic description of contents or features of an image) are stored and managed by an appropriate code database management system, and image data are stored and managed by a different file system. Between these two different types of data, a link is established by appropriate pointers stored in each entry of the code database. As data are retrieved from the code database, corresponding images will be obtained via the pointers described above. The advantages of this kind of image database are that the system's configuration is simple and that it maintains the integrity of conventional code databases. Practical design consideration of this type is described in [TANG 1981].

The other type of image retrieval operates through image content itself rather than through secondary information. Queries may be made by specifying the features or the structures of image contents, or by simply presenting an example image to the system. In the latter case, some features or structures of the image presented are extracted by appropriate image-processing programs, and this information is used in queries. This is usually called *similarity retrieval* since the image retrieved is similar to the one presented [LEE 1978].

The final goal in image database research may be a system which permits this similarity retrieval, but its realization is considered very difficult, mainly because there is no general method for extracting features and structures of image contents. If we could impose some restrictions on the types of images to be dealt with and on the complexity of queries, we might build a similarity-retrieval image database system.

The first type of retrieval strategy is the basis for an image data management system. Several systems of this kind have been used for managing Landsat images [BERNSTEIN 1980]. In applications to the human sciences, systems of this kind may be also useful to archive various kinds of image data and retrieve by means of secondary information.

An image data management system has been implemented and used for ethnological studies at the National Museum of Ethnology [HACHIMURA *et al.* 1983]. It involves a relational database management system named QBE (Query-By-Example) for storage and management of coded data associated with each image, and utilizes QBE's highly approved interface facility. Commands for image display are newly incorporated into the standard QBE system, and users can display images which satisfy retrieval conditions imposed on an associated code database.

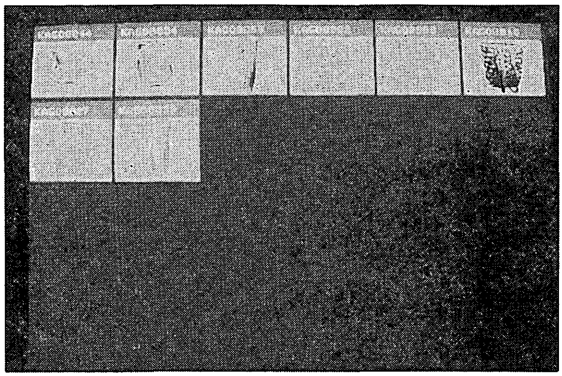
Fig. 9 shows an operational example of this image data management system for a collection of images of bamboo basket. Such attributes as dimensions and common names, stored in tabular form, are managed by the QBE system. A sample query made on this table, shown in Fig. 9(a), means "display material number and associated image name of the basket whose height, width and depth are all greater than 40 cm." The resulting table, containing the material number of baskets satisfying the query condition is shown in Fig. 9(b). In this resulting table several image-display commands "DISP." are placed in the leftmost column of the table to display images which correspond to that particular data. Fig. 9(c) shows images obtained by this query.

KAGO	BANGO	YOBINA	TATE	YOKO	TAKASA	SHUSHUCHI	IMAGE NAME
	P.		>40	>40	>40		P.

(a) Sample query

KAGO	BANGO	IMAGE NAME
DISP.	15284	KAGO0044
	Z72	KAGO0045
DISP.	7140	KAGO0054
	Z74	KAGO0056
DISP.	Z76	KAGO0063
	16392	KAGO0064
	21676	KAGO0066
DISP.	3683	KAGO0002
	2854	KAGO0003
	Z67	KAGO0005
	5079	KAGO0006
	5796	KAGO0007
DISP.	Z68	KAGO0008
	Z70	KAGO0011
	Z71	KAGO0015
DISP.	16394	KAGO0016
DISP.	4108	KAGO0027
DISP.	4284	KAGO0039

(b) Display request



(c) Images retrieved by the query

Figure 9. Image Data Management System

Constructing a collection of image data and a corresponding attribute database is another annoying problem. The Image Input and Automatic Measuring System for Artifacts of the National Museum of Ethnology, described above, might lighten the burden of constructing image databases of museum materials. When an object is placed on the turntable, the system takes three quasi-orthographic images and one oblique image which are transferred to some large-capacity storage devices. There the size of the object is automatically measured and the data transferred to a code database. It takes only about 15 to 20 minutes to get these four pictures and derive an object's dimensions from them. This system may thus be used as a data-entry device for image databases.

APPLICATIONS OF COMPUTER GRAPHICS TO THE HUMAN SCIENCES

Computer Mapping

The computerized techniques for producing maps include compilation, storage, transformation and display of geographical data.

The human sciences require the superposition of different thematic maps, and the production of distribution maps from described relations between location and subjects. These requirements are relatively easy to realize. Beyond them, however, sophisticated and integrated geographic database systems have also been sought to facilitate retrieval of geographic entities through various techniques: logical and graphical queries, manipulating and transforming spatial map data, and displaying it in a variety of forms. Research on this kind of geographic database system is currently in progress at a number of institutions [NAGY and WAGEL 1979; FREEMAN and PIERNOI 1980].

The earliest contribution in the computer mapping field was SYMAP. Developed about 20 years ago, it is still widely used today. Its use of line printers as its standard output device and ease of implementation at most computer installations may be the reason why it remains popular.

After the development of SYMAP, research on computer mapping continues at the Laboratory of Computer Graphics and Spatial Analysis of Harvard University. Among the various computer mapping programs published during the course of the research, ODYSSEY is the most recent product to integrate all its programs into a single system [DUTTON 1977]. These innovative works at Harvard introduced many computer applications into non-technical fields [*Harvard* 1978].

In Japan, intensive work at the University of Tokyo created the geographic information system named ALIS [KUBO 1984]. This system is initially designed for urban research, but it is open to general researchers at the University Computing Center and is widely utilized for many mapping applications.

Computer mapping may be one of the most important computer applications in ethnology and archaeology. Some regional ethnographic data are better analyzed by visual representation than by symbolic description. Originally, spatial data are best understood by representing them spatially on a display screen. As an aid for conception, an interactive system might be most desirable. The systems mentioned at the beginning of this section operate in batch mode. By contrast, in interactive systems commands or queries are inputted through a keyboard, and resulting maps or figures are directly and promptly presented on a display screen. Interaction encourages experimentation, speculation and hypothesis-formation, essential activities in all researches.

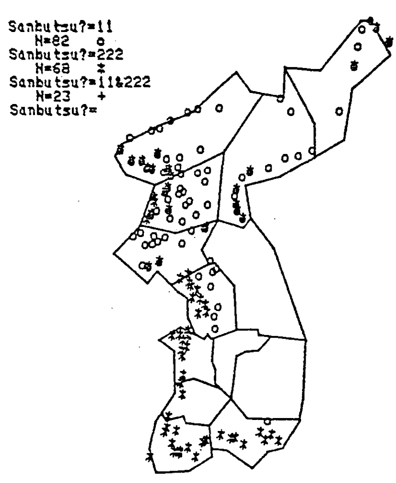


Figure 10. Example of Interactive Mapping

The example of interactive systems presented in Fig. 10 has been developed and used at the National Museum of Ethnology. It analyzes the distribution of products on the basis of data extracted from old Korean ethnography. Although the scheme of query is very simple, it may help researchers to discern the underlying relationships among products or between products and geography.

Shaded Graphics

Recently computer graphics techniques have been used to synthesize very realistic images, like still pictures and outdoor scenes. This is referred to as *shaded computer graphics.* The representation of three-dimensional objects is achieved by shading on their surfaces rather than just drawing their outlines. This graphics processing requires much computation because the brightness at each point in the image plane has to be calculated according to the geometric configuration of light sources and objects. Therefore, it usually takes much time to produce each single image frame.

These techniques are currently being used to produce, for example, animation film for entertainment [Crow 1978]. They are, however, of great significance in science, engineering and the human sciences, especially for producing graphic images to illustrate and display results of simulations. Visually expressing interim findings of ongoing research might further stimulate new ideas.

Another viewpoint is that by means of this technique we can synthesize various images from a single set of data. Possibilities include changing the geometric relations between objects, light sources and a viewpoint, and changing colors of objects or backgrounds. The capability to make virtual cross-sectional images implies the possibility of constructing databases of three-dimensional object shapes. In ethnology or any other study concerned with material culture it is desirable to deal quantitatively with three-dimensional shapes. Although we cannot store real three-dimensional objects in the computer, we can, if we have stored data expressing the three-dimensional structure of objects in the system, reconstruct them virtually and produce views from any direction. Hence even if we do not have a collection of real objects, we can examine their shapes as if they were there.

Fig. 8 demonstrates realization of this approach. (See page 134.) Fig. 8(a) shows the right half of a Nepalese wooden bowl in cross-section. Since this bowl was made on a lathe, it is rotationally symmetric about its axis, and its three-dimensional shape may be reconstructed from its cross-section. First, the rough shape is reconstructed and displayed by a wire-frame model in Fig. 8(b). Although hidden lines are removed to express solidness, it suffers from lack of reality. By specifying a position of light source relative to an object and a viewpoint, each surface on this wire-frame model can be shaded. In Fig. 8(c) the object gains solidity, but it is very squarish and less real. A final result, obtained by applying a surface-smoothing algorithm to Fig. 8(c), is shown in Fig. 8(d). Of course, changing the relative geometry among the light source, object and viewpoint can generate different views, and surface colors may be selected at will. Fig. 8(e) shows a cut-model display of this object; the cutting planes can be specified arbitrarily.

Thus, by merely storing data of cross-sections, various realistic views of objects can be reconstructed as if they really were in computer storage. Cross-sections can also be obtained without damaging the material.

Human Body Motion Display

A somewhat special application of computer graphics is human body motion display. The need for storing and displaying movement stems originally from choreographers, who have to teach dancers by demonstrating figures repeatedly. This problem, long recognized by professionals, has generated a number of notation systems to describe human body movement. Among them, *Labanotation*, developed by R. Laban, has achieved more popularity than the others [HUTCHINSON 1970], but because any human movement is very complex, a notation system is inherently complicated and difficult to master.

Efforts to use a computer to simplify movement notation include [LANSDOWN 1978; BADLER and SMOLIAR 1979; BROWN *et al.* 1978]. The last developed the graphics system to prepare Labanotation dance scores, and Singh *et al.* proposed a graphics editor for another movement notation system, *Benesh Notation* [SINGH *et al.* 1983]. Systems for generating human figures in motion from Labanotation-like description are described in [CALVERT and CHAPMAN 1978] and [WEBER *et al.* 1978]. Subjects related to these systems are also found in [BARENHOLTS *et al.* 1977] and [SMOLIAR and WEBER 1977].

Beyond European style choreography, which Labanotation was designed to record, the analysis of human body movement is also required in the study of non-verbal communications and of ethnic dance. The computer-aided movement notation systems described above, in addition to their utility as database systems for human movement, have possibilities as analytic tools in these research fields.

For the description and display of human movement, the author's group has developed an experimental system, in which movement is described by two distinct methods [TERAI 1984]. One is a basic symbolic notation, named BN, which combines alphanumeric characters. The basis of this notation is a modeling of human physiology by body segments and joints, the movement of each joint being specified explicitly, just as in the Labanotation. BN is also used to define movement commands, which can be used to describe stylized human movement.

Another method for movement description implemented in this system is a high-level formal language, named MDL, which has some properties of control structures like iterations, conditional branches and subroutines. In this high-level description, however, the exact individual movements of the human body or its parts are specified by movement commands embedded in the context of MDL and defined in advance by using BN. This complementary use of two description methods at different levels, one micro- and the other macro-scopic, is a special feature of this system.

An example of movement specification by BN is shown in Fig. 11. Fig. 12 shows movement described by the MDL language, where two subroutines, "turn_a"

		left								support				right												
		arm				leg								leg				arm				torso				
		F	W	E	S	T	A	K	H	0	1	2	3	h	k	a	t	s	e	w	f	P	L	R	C	B
1	10		S 0 – 2									0a 0 + 2								s 0 – 2						
2			S – k 2								4A 0 + 2	0a 0 + 2							s + k 2	e + i 2						
3			S 0 – 2								0A 0 + 0								s 0 – 2	e 0 – 2						
4			E + i 2	S + k 2							0A 0 + 0	4a 0 + 0								s – k 2						

Figure 11. Movement Notation: BN

and "walk," are called by the main program, and movement commands "step_l," "step_r" and "turn," are embedded in these subroutines. One of the frames generated on the graphic display is shown in Fig. 13, where a wire-frame model of the human body is used.

Art, Education and Other Topics

From the early stages of computer development, graphics techniques have been attracting people engaged in creative art, and a number of works have been created by using the computer as an artist's tool [CSURI 1974; SVEISON 1978; MCMAHON 1981]. Recent development in techniques to generate very realistic pictures has provided painters with new paints and canvas. Until recently, though, computer-generated images were restricted to geometrical patterns or objects, but now the *fractal* theory permits synthesis of irregular natural scenes, like mountain terrain, woods, and clouds [MANDELBROT 1977; CARPENTER *et al.* 1982]. Computer graphics techniques also produced sculpture [LAUCKNER 1977], and three-dimensional animation [CSURI 1977].

Another important application area of computer graphics is education. In science teaching these techniques have shown the results of simulating physical phenomena [MCKENZIE *et al.* 1978]. Most of the modern CAI (Computer Assisted Instruction) systems employ computer graphics techniques to increase efficiency in man-machine interface [BITZER and JOHNSON 1971].

Specific examples of educational computer graphics application in the human sciences are CAI courses in special language; Sumerian [BROOKMAN *et al.* 1981] and ancient Egyptian [DECKER *et al.* 1981]. Both are implemented on the well-known CAI system, PLATO [BITZER and JOHNSON 1971].

Computer graphics have been extensively applied in archaeology, where various kinds of spatial and graphical data, such as topographic maps and ancient patterns, are frequently dealt with [UPHAM 1979]. Badler *et al.* have developed an interactive

```
PROGRAM steps
    INT i;
    BEGIN
        turn_a(90.);            /*turn to the left*/
        i=4;
        WHILE {i>0} DO
            BEGIN
                walk (50., 10);         /*step_width=50*/
                i=i-1;                  /*speed=10*/
            END
        turn_a (180.);                  /*turn on his heels*/
        i=5;
        WHILE {i>0} DO
            BEGIN
                walk (40., 20);         /*step_width=40*/
                i=i-1;                  /*speed=20*/
            END
        turn_a (-90.);                  /*turn to the right*/
    END.
SUBROUTINE turn_a (angle: FLOAT)
    CHAR ca;
    BEGIN
        IF {angle≥0}
            THEN  ca='A'+angle/15;
            ELSE  CA='a'-angle/15;
        turn(ca);
    END;
SUBROUTINE walk (step_width: FLOAT, speed: FLOAT)
    CHAR ctl, ct2, cs;
    BEGIN
        ct1='0'+10/speed;
        ct2='0'+100/speed-ct1 *10;
        cs='A'+step_width/BOL [3] [3] *4;
        step_l (ct1, ct2, cs);
        step_r (ct1, ct2, cs);
    END;
```

Figure 12. Human Body Movement Description by MDL

system to assist in analyzing the spatial distribution of various objects from excavated sites [BADLER and BADLER 1978].

Other usage of graphics systems for social scientists is described in [SCHNEIDER *et al.* 1976], in which general graph plotting software and graphical data analysis tools are introduced.

CONCLUSION

This article has surveyed the applications of image-processing and computer-graphics techniques in the human sciences. Topics are drawn mainly from ethnology and archaeology, where until now research efforts have been concentrated. This focus may result from the fact that these disciplines have characteristics of field science

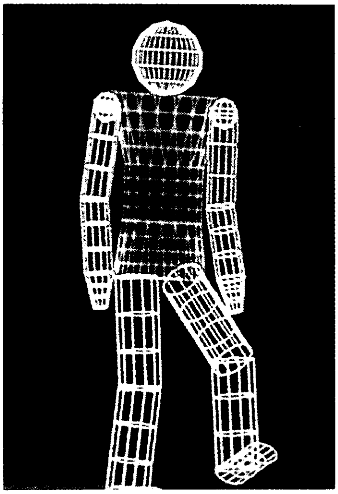


Figure 13. Sample Frame Generated from the Description

dealing with various kinds of pattern data, especially image data.

Compared to the variety and history of applications of computer graphics, examples of image-processing applications are still very few. Researchers who can use special image devices, such as image input and display devices, are limited, and image-processing algorithms are unfamiliar to non-professionals of computer science. Processing of remotely sensed images, however, may play a leading role in introducing image-processing techniques into these disciplines.

Things to be done next will be to develop an end-user-oriented, easy-to-use image-processing hardware and software system, and to win acceptance for it from human science researchers by showing attractive processing examples. It should be noted, however, that computer processing is not almighty; it may require a good deal of interaction by actual users of the system. Hence, the key point is to establish good cooperation of researchers in both the human sciences and computer science as in other interdisciplinary fields, and then to have the researchers use the interactive image-processing system.

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