A CYBERNETIC APPROACH TO PREDICTION

with an outline of an adaptive optical computer

by

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SUMMARY

Since the pioneering work of Kolmogoroff and Wiener the use of computing devices to solve problems concerned with the prediction of future states of a time series has stimulated a large amount of research. Despite all this, however, the results have been disappointing. If significant progress were to be made in this field it would lead not only to the possibility of forecasting economic events, the weather, earthquakes, epidemics, and so on, but also to the possibility of simulating these systems. Approaches involving the programming of a computer to carry out this task run into the difficulty of defining the variables involved in a precise enough manner, whereas using the computer to investigate all the past events of that time series requires a large processing time and an enormous memory store.

This thesis examines an approach to this problem which involves the use of a device for processing information in a parallel manner. The system envisaged consists of a holographic recognition device controlled by a digital computer - a combination of analogue and digital techniques. The principle of this device is that developed by Gabor and others, and allows the system to learn to predict the future of a time series.

The system learns to predict the future of a time series by using a past length of the time series as a training set. Using this training set it attempts to predict the next values of the time series, which can then be compared with the actual time series. The system, then, attempts to optimize its prediction by minimizing the error between the predicted and actual values.

PREFACE

The idea for this thesis evolved from work I was engaged in while working for the South Eastern Gas Board. This work was an attempt to use a computer to predict future gas demand, so that gas could be produced more economically. The problem, here, is essentially to predict future values of a time series.
Time series occur im many situations so that the thesis applies to a much wider field than just gas demand.

One of the pioneers in the analysis of time series was N. Wiener and his ideas formed a starting point for this work. Another source of inspiration was D. Gabor who, not only put forward the concept of holography, but also, with his co-workers, the concept of an adaptive, universal, non-linear filter. The third strand of this thesis was the idea, put forward by many, that a large number of optical phenomenon can be described in terms analogous to electrical filters.

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C O N T E N T S

INTRODUCTION

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0.1. The Analogue-Digital Duality

Recent theories (HYDÉN, 1970; PRIBRAM, 1971) suggest that the brain processes information in two distinct ways. Information is transmitted to and within the brain in a digital or discrete form, but the actual extraction of meaningful - that is meaningful to the brain - information is performed in an analogue or continuous manner. Evidence for such theories comes from electroencephalograph studies (LI and JASPER, 1953; MORRELL, 1967). Present day control systems process information in the opposite way. The input information, from sensors, is usually in the form of an analogue signal which is then processed by a digital computer (BEER, 1967).

Similarly, models of the brain and organic control systems either implicitly or explicitly involve some form of analogue information processing as soon as the design attempts to ensure an adequate response to a "real" environment. Thus, though a Turing machine (TURING, 1937), an Uttley classification machine (UTTLEY, 1956) and a digital computer act on information in a purely digital manner, they can only deal with an environment which is controlled within strict limits by an outside agency (e.g. the Turing machine acts on a papertape). Machines, such as Ashby's homeostat (ASHBY, 1952) and Uttley's conditional probability machine (UTTLEY, 1956), which were designed to work in environments which are real, i.e. environments in which the effects of events which are detrimental to the survival of the system can only be countered by the system, either by changing the environment or by changing itself, and not by any outside agency, process information in an analogue manner. The homeostat has its trough, and the conditional probability machine stores probabilities which can have any value between 0 and 1. The output from these machines, however, is a digital signal, e.g. a pulse to step the uniselector on to the next position, or a pulse saying event B will happen because the probability is above a certain level. This arrangement also allows these machines to learn.

The term analogue implies the computation of a mathematical function in a continuous manner, usually in time, by a physical representation of that function. An analogue device, then, can be conceived as a black box, or filter, which converts an input signal into an appropriate output signal, in a similar way to a band pass filter converting an electrical signal of a wide band of frequencies into a narrow band. A large number of these filters can be realized in a digital form on a digital computer. There are, however, a large range of functions which are possible, but economically impractical, to represent on a digital computer in such a form. Of special interest in this class are those functions which represent the analysis of data, which can be in the form of a time series, from the point of view of extracting meaningful information, i.e. information that enables conclusions to be drawn from apparently random events. It is possible, however, to design an analogue machine or filter to carry out this computation. The importance of such functions is that future states of the environment can be determined from the present and past states. It also implies that the future of the environment can be predicted for any set of present or past states allowing for a simulation of the environment and hence control of it. The mathematical analysis and design of such time series filters was pioneered by Wiener (1949) and Kolmogoroff (1942), but such filters are only capable of being designed for special limited cases. The basis for the analysis of such series is the Fourier series, integral and transform, which enable the series to be represented as a polynominal, the larger the number of coefficients the more accurately the series is represented. As stated, the actual calculation of these coefficients, especially for a filter representing a non-linear series could be impracticable and this has led authors (GABOR, 1954; GABOR, WILBY and WOODCOCK, 1960) to suggest that a universal filter could be built which would optimize its response by learning. Such a learning filter could be used as a universal simulator for systems such as large petrol refineries, weapon systems, countries' economies, etc. which cannot be subject to experimental tests, but for which it is important to know how they will react in certain contingencies. There is also no logical reason why the filter should not be capable of pattern recognition and so be a universal translator.

Such a filter need not only be concerned with electrical signals, for information can be transmitted in a number of ways - sound waves, microwaves, coherent light, and so on. Transmission systems such as optical ones allow information to be transmitted in a parallel as opposed to the serial manner in an electronic channel. Over the past decade a vast amount of work has been carried out to unify optics with communication theory (LEITH and UPATNIEKS, 1962; ELIAS, 1953). The stimulation has been the application of the laser in communications engineering and the development of the hologram which can, by means of a wave form (e.g. light, sound, microwaves), record a scene and then reproduce it in the original three dimensions. The recorded hologram can then be conceived of as a filter which, when illuminated by a source of the correct wavelength and coherence, will reproduce the original wave front from which the hologram was constructed.

Not only is a hologram a filter, it is also a memory and can store more information than more conventional computer memories. Also, the information is distributed over the whole of the hologram, enabling a reconstruction of the original image even if large areas of the hologram are destroyed. These properties of holograms make them more analogous to the human memory than the ferrite core, disc, magnetic and paper tape "memories" of a digital computer (PRIBRAM, 1971).

It would seem possible, then, to construct a universal filter, using concepts from holography, analogous to the human brain which would be able to simulate, predict and control systems requiring more than three independent parameters (the apparent limit of human intelligence) to describe them (GABOR, WILBY and WOODCOCK, 1960), especially if the filter was part of an intelligence amplifier. The potential for such a device would be enormous.

0.2 Logic of Prediction

Though it seems paradoxical, the universe on which a system acts is both internal and external. Internal, in the sense that all the system can know about the universe, is that which can be in some way represented within it. External, in the sense that a system's environment determines whether a particular action is successful or not. The models from which a system generates its strategies are merely internal representations of the environment and must be limited by the bandwidth of its sensors. If the sensors are very limited, this can lead to "stupid" behaviour even theough the system is acting rationally from the standpoint of what it conceives the environment to be. To make a distinction between rationality and intelligence it is possible to define rationality as subjective, i.e. it is the justification of a particular behaviour pattern in accordance with its own belief structure, and intelligence as objective, i.e. the justification of a particular behaviour pattern in terms of appropriateness to the particular environmental situation. Thus, a digital computer devoid of suitable peripherals, so that is has no direct communication channels with the real world, is merely a deductive logic machine, acting according to the principles inherent in its program, and so by this definition cannot be intelligent, just rational.

A rational being is one who seeks coherence within the universe or, which is the same thing, within its representation of it. It believes the universe can be understood and controlled, that is, it represents a true reflection of the environment. This leads to a picture of the universe as basically unchanging in time, just as logical statements are as true today as they were yesterday, and will be tomorrow. Science can be considered as being concerned with the changeless, history with chaos (BROWN, 1956). Unless things are changeless in time, prediction becomes absurd. On first sight it seems obvious that objects do change with time, babies grow to become old people, cliffs crumble away, and so on. The problem is, thus, how can an object such as an animal or plant be called by a name that implies that it is really the same object though in different periods of its existence it has different appearances and characteristics or, alternatively, why if it is really the same should it change its appearance and characteristics? A logic is required in which these apparent contradictions are resolved - so far no such logic has been evolved.

A possible solution is to regard change as occurring very slowly compared with the human reaction time and anything occurring any faster would be undetectable (BROWN, 1956). The continuity of existence can then be viewed in terms of the continuous processes in the brain, which only appear as changes when certain thresholds are reached. Even the digital signals in the brain can be considered as analogues if they are viewed in terms of their frequency. Frequency and time are a pair of Fourier transforms, just as are spatial frequency and the angular spectrum, so time can be viewed as a fourth dimension of space. However, time as experienced appears to be different to the others in that it is unidirectional, and that though one can go back through memories, one can only act in time on things at one particular instant. In fact it is impossible to communicate with an individual whose time runs the opposite way (WIENER, 1948). Thus there is freedom to alter the future but not the past.

Cybernetic machines tend to be logical machines, such as Uttley's machines (UTTLEY, 1956), or alternatively machines which operate in time on principles based on the mathematics of the Fourier transforms, such as Gabor's filter (GABOR, WILBY and WOODCOCK, 1960). The Turing machine (TURING, 1937), though it appears to work in time, used time only to transform its logical analysis into a serial form, i.e. the output from the system depends solely on the input and state of the system but not on the precise instant the signal occurs. What is required is a machine working on a logic that can take into account time, as the equations of the second degree attempt to do in Spencer Brown's "Laws of Form" (BROWN, 1969). Time here is evolved in the division of a continuum.

It is now possible to imagine the synapses of the nervous system as being distinctions several crosses deep, the value of these distinctions being determined by an analogue mechanism, but as far as the external system is concerned, only capable of two states, depending on whether the threshold value is reached or not. This would mean that the time delays in the nervous system are a necessary requirement of the system.

The problem is, now, to make the system work in time; this can be done by making the system search for coherence of its prediction with actuality in a manner similar to Ashby's homeostat (ASHBY, 1952), i.e. using random displacements in the environment to cause the machine to move from one state to another. If the system has enough connection with the external environment there will be sufficient displacements to keep the system continually in motion. It is possible to think of time not in such a system but in the metalanguage used to describe it, i.e. time slices are taken as the basis for description (WOODGER, 1939).

Time series are a record of these time slices and appear in economics, social sciences and many other disciplines. A time series can be a continuous record (the interval between the time slices are infinitesimally small) of a series of events, but because of limitations in detecting and measuring events it is more likely that the series will be constructed from discrete data taken at equidistant time points. Usually the study of these series is the domain of the statistician because they are concerned with stochastic processes. These time series are generated by the systematic and stochastical logic of the system under study. To enable full use of such series for prediction or forecasting it is necessary to develop hypotheses which can be tested, so that the relevant parameters can be identified (VALAVANIS, 1959).

A synthesis can be made between the two apparent disparate fields of the analysis of time series and communication engineering. In the analysis of time series, methods involving probability theory and correlation are part of the traditional stock in trade of the statistician. The complex plane of function theory has a long history in communication technique, and now offers a new way of analysing time series, just as statistical methods offer new methods to the communications engineer. Fourier methods belong partly to the repertory of each for they occur in the theory of the periodogram and in the operational calculus, but they have been applied with a full awareness of their power neither by the statistician nor by the communications engineer (WIENER, 1949).

0.3. Models of Intelligence

Several cyberneticians have built machines to represent aspects of human intelligence. But how do we know if a machine is intelligent? Before we answer this question let us consider another, but similar, question "Can machines think?" Turing (1950) suggested that this question could be rephrased in terms of a game in which an interrogator put questions to a human and a machine. The interrogator was placed in a separate room and the questions and answers were relayed by a teletype or similar device. From the answers the interrogator had to decide which was the machine and which the human, while the machine attempted to mislead him. Turing argued that if the machine did well in this game one would be forced to the conclusion that the machine was capable of thought. The reason for answering the question "Can a machine think" in this way is that it enables us to divorce intellectual from physical capacities. Thus, if a machine performs well in tasks commonly believed to require intellectual powers, then we have to describe the machine in the same way as we would a human.

0.3.1. Models of Nervous Transmission.

A signal is transmitted along a nerve fibre by means of an electro-chemical change in the nerve membrane. The transmission of a signal in this way has certain characteristics, the main ones being that there is no preferred direction of propagation, the velocity of the signal depends only on the properties of the line itself; that the line will not transmit another signal during a period after the initial transmission of a signal, which means that if two signals travelling in opposite directions meet they will destroy each other, and there will be no reflections at discontinuities in the transmission line. The advantage of such a system is that, as the energy required for the transmission of the signal is supplied all along the line, there will be no attenuation even if the line has a large impedance (as long, of course, as there is a sufficient supply of energy). Models both of a mathematical and physical kind have been made. Models of the first kind were devised by Hodgkin et al (HODGKIN, HUXLEY and KATZ, 1949) on mainly empirical grounds and models of the second kind are exemplified by devices like the neuristor (CRANE, 1962).

0.3.2. Uttley's Conditional Probability Machines.

Uttley (1956) suggested that the resemblance to an animal of the internal representation of two external events could be explained in terms of the inclusive relationship of set theory and conditional probability. From the first of these concepts he developed a machine that could classify external events in terms of their properties, which he called a classification machine.

From the concept of conditional probability Uttley developed the conditional probability machine. The classification machine was incapable of learning and could mis-classify an object with an obscured characteristic. To surmount this obstacle Uttley suggested that instead of a unit having two states, i.e. one state if the event occurred and another if it did not, represented by, say, 1 and 0, the unit should be in a state represented by 1 when a set of properties occurs, and a state which can be represented by any value between 0 and 1, i.e. the conditional probability, as determined by past experience, if that set of properties does not occur. This was a conditional probability machine.

0.3.3. Gabor's Universal Non-Linear Filter, Predictor and Simulator.

The difficulties involved in the design of an optimum non-linear filter led Gabor (see GABOR, WILBY and WOODCOCK, 1960) to suggest that such a filter could be optimized through learning. He designed a filter which took the form of a flexible mathematical operation, capable of operating on the present and past values of any time series fed into it. The machine learnt by sampling the type of stochastic series which it is to filter or predict, together with the target function which it is expected to produce. The machine had a large number of adjustable parameters which were adjusted to minimize the error between its output and the target function. The minimization of this error was judged by the criterion of least mean squares, as used by Kolmogoroff (1942) and Weiner (1949) in their linear filter theories.

0.3.4. Homeostat.

The homeostat was a machine built by Ross Ashby (1952) to demonstrate ultrastability, i.e. it had the ability to keep its own variables within limitations which ensured that the system survived. It consisted of four units connected so that any disturbance of the equilibrium state of any of the units was compensated by the other units taking up different states. It was possible to build in a sufficient number of possible states so that the homeostat was able to find a stable equilibrium position no matter what excursions were taken from the equilibrium position.

0.4. Holography

The concept of holography was introduced by Gabor in a paper in 1948 and further developed by him (1949; 1951a; 1951b; 1951c and 1952). He chose the name holography from the Greek, as the new technique involved the recording of the whole of the message. Thus the total information in a wave front, including phase and amplitude, could be recorded, as opposed to the normal photograph where just the amplitude was recorded. The phase of a wave front is a relative parameter, requiring an arbitrary standard to which it can be compared. In holography this was achieved by causing two wave fronts to interfere, one from the object and the other from an homogeneous coherent background illumination used as a reference. Gabor showed that this system was reversible, so that if the interference pattern of the two wave fronts was recorded on a photographic plate, the original wave front could be reconstructed by placing the photographic plate in the homogeneous coherent background illumination.

0.4.1. Holograms as Filters.

Along with the development of the principles involved in holography, attempts were being made to unify communication theory and optics (ELIAS, 1953 ; LEITH & UPATNIEKS, 1962) using such notions as modulation, demodulation, filtering and so on, to describe such phenomena as holography in optics. The hologram can be considered as a filter that changes the reference beam on the homogeneous coherent background illumination into the wave front of an object. The concept of Fourier transformations was also introduced into optics, thus allowing complicated spatial or temporal expressions to be expressed in the simpler frequency components which had been so fruitful in the analysis of electronic circuits. Conversely it provided a means for the calculation of complicated expressions of this nature by means of optical analogue computers, which could not be solved any other way. In this way a hologram could be considered as a filter which would be able to recognize patterns and be capable of prediction.

Pattern recognition is based on the ability of the hologram to pick out from a group of objects those whose "images" are recorded on it. Suppose A and B are two coherent radiating objects, for instance they may be any objects illuminated by a sufficiently coherent laser, if the radiation is capable of creating in a certain plane an interference picture - a system of standing waves, then a photographic plate may be placed there and a hologram obtained. By illuminating the hologram A and B with an ideal copy of the initial wave front of one object a faithfully reconstructed wave front capable of faithfully imaging the other object will be obtained. The hologram will transmit only that part of the spatial spectrum which is close to the spectrum recorded on it. Thus it will respond only to the image of one of "its own" objects, with the condition that the object be placed in the appropriate position. Normally one of the objects will be a plane or spherical wave front, i.e. reference beam. If, for instance, the object

B is a combination of point sources comprising the code letter, then the hologram A and B illuminated by the letter A permits the reconstruction (i.e. the extraction from the hologram) of the code B. Using recordings with various angles on the same hologram it is possible to record a large number of letters, thus providing a new channel of communication between man and computer which will liberate the operator from the manual introduction of data. Moreover, it might be possible, using this method to enable a computer to recognize multidimensional images.

There are a number of beams which correlate sharply with themselves, i.e. those which issue from a fingerprint or those from a Chinese idiogram, and in an extreme case also those from a piece of frosted glass. They correlate sharply with themselves in the sense that the number of invariants in the beam greatly outnumber possible variants, i.e. a fingerprint may be presented in a limited number of ways, its size and orientation may be changed, but there are a large number of properties of the beam that are not changed when it is transformed in size and orientation. This means that there is a large amount of redundancy. Thus if the beam is considered as being made up of beams, A, B, C ...... and so on, each beam A, B, C .... is capable of uniquely defining the total beam. Then, whenever the total beam is present there will always be a sub beam untransformed, so that if the hologram is constructed of A + B + C .... ..+ code, the code will be produced no matter how the total beam is transformed. Hence it is quite possible, for instance to translate by means of a hologram a Chinese idiogram into its corresponding English sentence and viceversa. In other words, a hologram can be a universal translator.

0.4.2. Holograms as Memories

Holograms have several properties similar to human memories in that the information is stored in a diffuse manner, so that an image can be reconstructed from a small fragment of the original hologram.

Also such memories are associative, i.e. the choice of the necessary information is made using a certain sign rather than the address of the cell in which it is stored (See PRIBRAM, 1971).

The most pratical way of storing such memories is in deep, or volume, holograms (DENISYUK, 1962; VAN HEERDEN, 1963) which are three dimensional interferograms. The wave front interferes with the coherent background throughout the thickness of the emulsion and so does not yield a superposition of the real and imaginary images. The information stored in this type of hologram turns out to be much richer than that contained in the convential hologram. A number of holograms can be stored in the same volume by varying the angle of incidence of the beam and/or its wavelength. The image can then be reconstructed by illuminating the hologram with coherent radiation of the correct wavelength and orientation.

0.4.3. Acoustical Holograms

Holography is a phenomenon of waves and, as such, sound waves, or even microwaves, could be used instead of light waves for the formation of a hologram. In accoustical holography the interference pattern is recorded by scanning the plane of the hologram with a microphone or similar sound detecting device. This pattern is transferred to a photographic plate, either by photographing an oscilloscope representation, or by using the output from the sensing device to drive a device to which the photographic plate is sensitive, such as an electric lamp bulb. This photograph is then reduced, so that the image can be reconstructed using coherent light illumination, by the ratio of wavelength of the sound to that of the reconstructing light illumination. Another method is to allow the sound wave to interfere on the surface and then to use this disturbed surface to form an optical hologram, which is read by laser light.

As the recording of the acoustical holograms depends on the scanning of the plane of the hologram, and the reproduction of the interference patterns is via linear electronic detectors, there is no need for a reference wave as this can be superimposed electronically afterwards (FRITZLER ET AL, 1969). Also the hologram can be recorded as a phase hologram without the need for amplitude information, which greatly reduces the amount of information that is required to be stored (METHERELL, 1969).

0.5. Intelligence Amplification.

Ashby (1956) pointed out that the industrial revolution was brought about by the ability of men to amplify their muscular strength by means of machinery. Nowadays amplification also occurred in control situations. An operator could control a process by setting in the limits to a central controller, i.e. controls the controller, which in turn could control a large number of sub-controllers. Intelligence, defined here as the ability to solve problems, especially those of a complex nature, could be thought of as the selection of the correct solution from a large number of incorrect options. The generation of solutions could be carried out by a random process, the application of intelligence was to select the appropriate solution - just as a gardner selects the appropriate sized stones from the soil by choosing a sieve with the appropriate mesh.

The mechanism of such selection could be conceived in terms of an Ashbian homeostat(ASHBY 1952). Suppose that two units of Ashby's homeostat were connected together, one could be an homomorphic representation of the environment and the other a representation of the desired states of the system. Thus it would be possible to select a particular desired state, say, unemployment should be less than a certain number; the machine would generate in a random fashion a large number of possible stable economical environments, all of which would be vetoed in turn until one which contained the desired state was generated. The definition of a stable environment could also be selected, say an economy with neither growth nor contraction in real terms, so that economical environments without these conditions would be vetoed even if the unemployment in them was less than the maximum laid down. The difference in the criterion laid down in each unit is that the choice of the maximum number of unemployed is a choice that can be made by a man. The fact that the environment is stable is determined by forces outside the control of mankind, just as the force that causes unsupported bodies to fall is outside the control of man. It could, of course, be argued that the choice of the maximum number of unemployed is just as determined, i.e. if there are more than this number unemployed, society becomes unstable. Thus a hierarchy of such intelligence amplifiers can be built up, greater selection taking place at each level. Ashby(1956) described the mechanism of the intelligence amplifier in terms of the search for a plumber. Suppose a plumber was required, only two might be known, so a one bit selection was made in deciding which one to telephone. If now the telephone directory were consulted the selection of one number from say 50,000 was a 15.6 bit selection, i.e. a one bit selection determined a 15.6. bit selection. This is because there was a two stage process, so amplification could take place. A similar two stage process takes place in the hierarchy discussed above.

The criterion for the environment to be stable, or tenable, or whatever, is, as said before, determined by factors outside the control of man. Thus, the choice of criteria may be from experience or from a model of the environment that has worked in the past. It may be considered that the only solutions that have worked in the past were those of zero growth, or this criteria may be evolved from a consideration of the "logic" of the situation. However, all that is expected from a criterion is that it guarantees that a particular solution will continue to be an appropriate solution for a suitable length of time. A particular solution might have zero unemployed for a short time but, because of its nature, might lead to vast unemployment in the long run. So that if the unit representing the environment had a predictor, the number of criteria would again be reduced, leading to greater amplification.

Two problems have now evolved, one is due to the fact that any representation of the environment is likely to be homomorphic and not isomorphic, and the other is that the hierarchical nature of the amplifiers leads to a state where no beginning can be made, a sort of infinite regress is generated. Both problems can be solved by connecting the total system to the environment, i.e. use the environment as the target function. Thus, an acceptable figure for unemployment could be generated in a random way and tested in the environment. Similarly the models of the environment could be tested. Thus the optimum programming for such a machine would be to allow it to optimize itself through a learning process.

The time taken for a random search through all of the solution space could be reduced by the use of constraints, so that only a search of those areas most likely (from previous experience) to yield results is made. Also the machine would not start "cold", there would be previous experience of other machines to draw upon, just as the human child draws on the experience of other people during its learning process (ASHBY, 1956).

0.6. Possible Cybernetic Solutions.

As the economies of industrial societies become more and more complicated there is a need for more sophisticated methods of forecasting in order that planning can be more efficient. This planning need not lead to a loss of freedom as the accurate simulation of possible environments should enable a true choice to be made of the kind of society that is required. Thus, the more accurate forecasting, or simulation, of economies and other complicated systems there is, the greater degree of freedom, just as the more knowledge an individual has the greater is his freedom of action.

0.6.1. Computer Models Used for Prediction.

There are a number of computor models which can be used for prediction, typical of these are:-

1) Box and Jenkins

2) Regression Analysis

3) Muldo (Harmonic Analysis).

0.6.1.1. Box and Jenkins

This technique optimizes a model that is intuitively chosen by the user, obviously if the type of model is ill-conditioned to the data the result will be very poor and meaningless. Box and Jenkins actually analysed with this method the forecasting of the number of airline passengers for a period of several years, using past data (BOX and JENKINS, 1970).

The optimal forecasts of future values of a time series are determined by the stochastic model that describes the series. Therefore, a class of stochastic models must be developed which is capable of representing not only the stationary behaviour, but also non-stationary behaviour of the kind that is encountered in practice. A series is stationary if its properties are unaffected by a shift in the time origin.

0.6.1.2. Regression Techniques.

This programme evaluates the coefficients and the various weightings, the optimization criteria being to minimize the residuals (similar to Box and Jenkins). Once the parameter coefficients attained values which did not vary by a certain magnitude, the programme examines the variables and rejects those which have an insignificant contribution to the model. This method has the advantage that there is no need to know much about the series under consideration, but has the disadvantage of requiring a large computer memory (CHADWICK, 1969).

0.6.1.3. Muldo Approach.

This method entails the analysis of the time series into the various harmonic cycles involved in it - carrying out a Fourier analysis of it. This suffers from the disadvantage that the mathematical analysis of such systems shows that future events affect values of the coefficients being calculated (CHADWICK, 1969).

0.6.2. An Adaptive Computer Solution.

A possible solution is to write a programme that will simulate Gabor's filter, and use a learning process to optimize the coefficients of the polynominal, which will be similar to the Muldo approach .

0.6.3. An Analogue Predictive Filter.

As stated before, the hologram can be considered as a filter, with certain characteristics.

It is possible to conceive of an adaptive hologram in the form of a cell. In this cell could be a material that became opaque if an electric field was placed on it, a Kerr cell, or maybe a colloidal solution, so that if standing waves were set up in it perpendicular to the direction of the reference wave, a form of interference pattern would be set up. If these oscillators (they could be electrical, ultrasonic, etc.) could then be controlled, then it could become adaptive.

The reference beam need not be from an external object, it needs only to be a coherent beam, for the actual beam representating the object could be fed to the oscillators. If there were several of these cells, one behind the other, and in certain of these the hologram was made permanent by "hard wiring" the oscillators, this image could be compared with previous ones and pattern recognition would take place.

If the recording mechanism was similar to that involved in the recording of acoustical holograms, i.e. the sampling of discrete points, the reference beam could be superimposed afterwards. If a method of this type was in use in the brain, the information that such a filter would act on would be the internal representation of the external world, not images from the external world. Thus the filter is dealing with a stream of pulses, not the wave front of light from a particular object and the amount of information required to generate the hologram would be less, especially if it was a phase hologram. The memory could be diffused throughout the brain as the sampling points need no longer be adjacent - the points on this hologram could be formed at the synapses. The ARAS signal would, thus, be a reading signal or carrier wave. If the output from these cells or holograms was of a digital nature, or frequency modulated, i.e. if, when the intensity at one point reached a threshold value, that pattern was recognized, these could be considered as units in any of the brain models discussed earlier - a two process device.

If a whole series of these devices acted on a signal in parallel they could alter the signal so that it was equivalent to itself displaced in time-prediction.

Chapter 1.

THE CLASSICAL APPROACH TO PREDICTION

1.1. Introduction

Prediction is concerned, by definition, with events in the future which, it is believed, are influenced by events in the past. The Romans used the entrails of a lizard to foretell the outcome of the pending battle, the formation of the entrails, it was believed, being somehow connected with the battle's outcome; this could be interpreted as either the present influencing the future, or the future influencing the present. Nowadays, being scientific, such predictions are based on calculations, or extrapolations, from present and past data. This leads to a belief in a causal chain running from the past into the future, whereas the Romans would have had no difficulty in believing in a causal chain running from the future to the past. The question is why this causal chain should run in any direction, this causal chain being somehow related to time. On the face of it there appears to be no difficulty in distinguishing between the past and the future. From the standpoint of the present it seems that the past is over, it is a memory, it is unalterable. The future, on the other hand, is still to come, there is no certain knowledge of it, and it can be altered. As Layzer (1975) put it "intuitively the world is perceived as extended in space but 'unfolding' in time, the present being the crest of a wave continuously transforming potentiality into actuality". Time can be considered as a river travelling towards the sea, and just like the river it can only flow downhill.

This direction of time was described by Eddington (1935) as the arrow of time. In living systems this arrow of time points in the direction of the development of more complex organisms and structures, both physical and mental. In evolution, for example, an increasing variety of ever more highly complex forms are being created by the mechanism of random mutations and natural selection. In the individual there is seen a greater differentiation of its parts to peform certain functions as the organism develops. Further, once Life has established itself there is a constant interaction between the organism and its environment, so that both are modified in such a way as to provide for a continuation of Life. The arrow of time, here, points in the direction of the generation of order or information; a simple state is transformed into a more complex one.

However, in the world of inanimate matter, the arrow of time points in the opposite direction, the direction of the destruction of order and information; buildings fall down, dead animals decay, fossil fuels become used up, the energy contained within the fuel being converted to forms that cannot be used. The distribution of matter and energy throughout the universe is becoming uniform, so that there are no undifferentiated structures. This represents the most probable distribution of matter and energy in the universe, just as a pack of cards leaves the factory in order, but with use and shuffling the chance of being dealt a particular card becomes more and more like one in fifty-two. The irreversibility process that destroys this macroscopic order is an example of the entropy that is generated by all natural processes. Entropy is usually, crudely, equated to the energy that is unavailable for work. It can also be considered as the number of internal states that correspond to the same external state. For example, in a hot gas there are a large number of internal states which correspond to the same pressure and temperature.

The second direction of time's arrow is governed by the laws of thermodynamics, particularly the second. It is possible, however, within the second law of thermodynamics for parts of a system to reduce their entropy, provided that there is at least an equal increase in entropy elsewhere in the system. Life, for example, is not an isolated system, and this increase of entropy only applies to a closed system. There is an input of energy, for instance energy from the sun is pouring in, enabling the system to keep its structure at the expense of destroying order in other parts of the universe. In this situation the system does not tend towards the thermodynamic equilibrium of maximum entropy, but tends towards another time independent state known as a steady state, which continues until the energy supply dries up.

The fundamental laws of physics do not reflect either of these two directions of time. At the microscopic level the motion of a single molecule does not generate either order or entropy. "Order" is a macroscopic concept, a property of systems made up of many particles. In the physics of elementary particles the world changes but does not evolve. So where does the arrow of time get its direction?

In this chapter it is proposed to look at where this irreversibility arises if it does not come from the fundamental physical laws, at entropy, at order, and at homeostasis, with particular regard to living organisms and the teleological language that is sometimes used in biology and cybernetics. The analysis in this chapter will, it is hoped, enable a logic or science of prediction to be developed in later chapters. But first, a look at the philosophy and logic of science will be taken, after all it was noted at the beginning of this section that it is the so-called scientific outlook that first introduced the idea of a direction of time with its roots in causal relationships.

1.2. Science and Prediction

Science, especially in the nineteenth century, acquired an aura of excellence, holding as it did the promise of control over the environment, exemplified by such phrases as "search for truth","the highest human endeavour", and so on. but what is science? Science is sometimes used as a synonym for rationality, and in this sense it is expected that intelligent machines will be able to conduct affairs more rationally or more scientifically. To put it at its most simple, science is what scientists do. There are, however, a number of competing theories as to what scientists do. Kuhn (1962) has put forward the view that there are two types of science, so called normal science and revolutionary science. In normal science there is a paradigm or theory which is accepted by all the practioners in that particular field, and scientists are involved in solving problems in the light of that paradigm. In a period of normal science, any failure to find a solution to a problem is a shortcoming in the individual and not in the theory. There will come a time, however, when it is obvious that there is something wrong with the original theory and so there will be a change to a better theory, when this happens science goes through a revolutionary period. The purpose, then, of the paradigm in Kuhn's normal science is to provide a framework within which nature can be discovered "rationally", but, because of its shortcomings as a theory, this will lead to its own destruction and a new, and better theory. In apparent opposition to this it has been proposed (**POPPER,** 1974) that science consists of the generation of theories which are then submitted to the criticism of others, and experiments in the real world, in an attempt to be falsified.

The problem with Popper's position, as Kuhn rightly points out, is how a theory can be falsified. No theory is an island, it is part of an interwoven net connecting a number of such theories. When Galileo showed the Jesuits the moons of Jupiter through his telescope, the

Jesuits pointed out that these moons might well be a function of the telescope and not of Jupiter (see LAKATOS, 1974). Thus to establish the theory that Jupiter has moons, it is necessary to establish an optical theory about the telescope, a physiological theory about the eye and so on. Even when a theory has been shown to be wrong, or to put it another way, when everyone agrees that the theory is wrong, there is still a problem, for in a number of cases a theory can be modified and developed to take into account such discrepancies, therefore should a theory be rejected as soon as it is falsified or should it be allowed to be developed to see if it can overcome the difficulty, and if so, how long should be given for this task? If any time limit is placed on the development of a theory, the same objections as were raised when it was proposed to reject a theory as soon as it was falsified again apply, but if no limit is applied this means that there is no permanent objective standards by which to reject or accept a theory, thus making science irrational (see for example, FEYERABEND, 1974).

Kuhn's solution to this problem was to talk about a psychology of discovery as opposed to a logic of discovery. Kuhn envisaged the change from one paradigm to another as similar to a Gestalt switch in psychology. Thus an individual scientist would suddenly "see" that another theory fitted the facts better than the present one, and this "view" would sweep through the scientists in his field like a religious revival or mass conversion. The difficulty here is that if Kuhn is to be taken literally there will be no other theories available, all there is is the single paradigm to which the scientist sticks no matter what, for no conflicting evidence is allowed. It is, however, probably the case that while the research scientist sticks to a particular paradigm for his work, he is still prepared to speculate on other possible paradigms in his spare time, as it were. It is only when the original paradigm is found to be wanting for a particular purpose that the other possible theories are entertained for his work. Feyerabend (1974) pointed out that a synthesis of these two views of science is possible. Instead of talking about periods of normal science and periods of revolution, Feyerabend talks about normal components and revolutionary, or philosophical, components which are always present in science. Theories are always being generated in science but it is only at certain periods of history that these new theories become evident to people outside a particular field. The reasons for the collapse of one theory and the rise of another at a particular time could be irrational in the sense that the reasons were outside that particular field. A chance discovery of a phenomenon in that field, or a discovery in another field of science, or even a new intellectual climate of opinion, could cause the switch; at various times in history the model taken for a "true" explanation has been different - mathematical, mechanistic, biological, evolutionary, teleological, and so on. Science is, therefore, rational in the sense that there is always a reason for a change but irrational in the sense that the reasons are not always the same; there is no standard objective criteria for a change. Feyerabend (1974) postulated the principle of tenacity, which is the advice to select from a number of theories the one that promises to lead to the most fruitful results, and to stick to it even if it encounters considerable difficulties. If, however, another theory can be used to accentuate the difficulties of the first theory while at the same time promising a means to their solution, then the elimination of the theory is urged by the principle of tenacity itself. Hence, for science to develop it is necessary to introduce and articulate possible alternatives, or, as Feyerabend expresses it, to adopt a principle of proliferation.

It would appear then that far from being mutually exclusive theories of science, they are merely two sides of the same coin. Both consider that the real world is the final arbiter as to the truth of a theory, but the observation of the world is not possible unless there is a theory in the first place so that irrelevant observations can be discounted. The differences are of viewpoint and emphasis, Popper being a philosopher and Kuhn a historian of science.

What kind of questions can science answer? The validity of an answer depends on the kind of evidence that is acceptable to the questioner. Thus, to the question, how did life on earth arrive at the state it is today, there can be at least two "true" answers. There is the answer which is along the lines of Darwin, and as evidence for its truth it produces such things as fossils from the external world, and there is the answer along the lines of Genesis which would produce as proof of its "truth" statements from a higher authority, such as the Bible. Thus, the questions asked by various disciplines of learning are of different ontological status, the evidence for the truth of a scientific theory coming from the external world. Scientific evidence that an artificial intelligent controller is controlling a process in a factory is that it is actually controlling that process in the factory, not that it appears to be controlling the process in some mathematical model inside itself.

Kuhn (1962) described the debates of prescience, with their universal criticism and uninhibited proliferation of ideas, as "often directed as much to the members of other schools as ....to nature". As a remedy to this situation Kuhn suggested the adoption of one of these ideas, using it to solve problems in the real world, and to see what happens. As has already been pointed out, such an adoption would not be a purely arbitrary one, but would be determined by previous experience, but to obtain this previous experience it would have been necessary to adopt a paradigm in order to achieve any order from the chaos. This immediately gives rise to the two related problems of perception and awareness.

It would seem easy to programme a computer with a single paradigm if we knew it, but cybernetics is interested in the generation of concepts, hypotheses which are then acted upon, be it by an artificial control system or the human brain. It is attempting to reduce Kuhn's psychology of discovery to a logic of discovery. It was the contention of Kuhn that the training of a human scientist consisted of teaching him to "see" a range of situations as being the same. Thus, a pendulum, a spring, an oscillating column of liquid, a wave and so on can all be treated as particular cases of the mathematical model known as simple harmonic motion, but it is necessary to abstract from a particular situation the relevant parameters. Conversely, a machine such as Uttley's needs to be able to perceive that there are two events A and B which are different, and have a box in which to put both of them. At a later time it might be recognised that A and B are in fact the same. Thus, for Van Heerden (1968) to use a time series to predict the future dodges the important issue of the selection of the right time series. To say that "the principle of induction is the only source of knowledge, both scientific and commonsense, of the real world" (VAN HEERDEN, 1968) is to miss the point that the observer is not passive, he only perceives events in the light of his previous experiences. This has led people (MEDAWAR, 1969) to propose that science is based on a hypothetico-deductive system, i.e. hypotheses are formed, the logical consequences of which are tested in the external world.

An example of this learning and refining of concepts can be given in terms of the development of intelligence in infants and young children. A long study has been carried out (e.g. PIAGET, 1953; PIAGET & INHELDER, 1956) on children of all ages which has led Piaget to postulate various stages of development. The infant begins by experiencing an almost undifferentiated totality, i.e. he has not yet learned to distinguish between what arises inside himself and outside, nor the various aspects of the "inner" and "outer" worlds. However, the infant has certain inborn needs and ways of satisfying these needs. This satisfying of needs leads to the recognition that certain objects are functional, e.g. can be eaten. After a while the child partakes in actions not designed to satisfy primary needs but "to produce interesting spectacles" as Piaget puts it. Gradually the infant becomes aware that there are discrete objects in an "outer world".

Later the infant begins to follow a moving object with his eyes, recognizing its invariance of form despite its movement. However, he behaves as if the object comes into existance where he first saw it, and passes out of existance where he last saw it. Thus, if an object passes in front of him and disappears he does not begin to look for it at the place where it disappeared, but at the place where it first appeared. If an object disappears behind another object he does not look behind it. The realization that it is meaningful to look behind the screen comes only when he is able to conceive of reversible actions (groups of two - Piaget), i.e. actions which can be undone by a second action, which provide a foundation on which he can erect the notion of permanent objects which can always be brought back to something familiar and recognizable by means of suitable operations (e.g. rotations, displacements, etc.).

The development of concepts in a child would then seem to depend on an interaction between the child and its environment, and a series of Gestalt switches in which he becomes aware of a new dimension, i.e. at a certain stage to simply expect an experience to repeat itself and the object to reappear where it first appeared, then to realize, by trial and error, or however, that it can be made to reappear where it disappeared by carrying out a certain action, such as removing the screen. Within his previous logical structure there is no reason why he should look there. Thus it would seem that is would be necessary that in order to develop an artificially intelligent system, a channel with a large band width is required between the system and its environment, so that it can become aware of evidence that suggests that its hypotheses are no longer relevant to the world, and so it can contemplate changing its hypotheses.

A further example from Bohm (1965) shows up the analogy between perception and scientific research. When a new fact is to be understood, as distinct from accumulating new knowledge, at first all that can be taken in is various bits of knowledge, the relationship of which is not clear. At a certain stage, however, in a very rapid process, often described as a "flash", understanding takes place. When this happens the learner says "I see", but what is it that he sees? He perceives a total structure in terms of which the older items of knowledge all fall into their proper places, naturally related, while many new and unsuspected relationships suddenly come into view. It is even possible to devise a mechanical analogy. Consider a cork disc through which a bar magnet is pushed, so that its north pole is on one side and the south pole is on the other. This cork is then placed in a bowl of water which is placed between the poles of a large magnet, so that the cork is"pulled" towards and then floats at the centre of the bowl. If another cork is added to the bowl in the same orientation as the first, so it again is "pulled" towards the centre, but on reaching the centre it is repelled by the first cork, so that they both float around in the centre. On adding a third, there is again a reorientation of the corks as the system tries to reach a position of minimum energy. If the fluid is viscous this reorientation is not gradual; when the new cork reaches a certain distance from the centre the rest appear to "jump" into their new position.

Professor Pask (1975) has suggested that learning and innovation are both the same process but at different levels. The important point is that the organism becomes aware of inconsistencies in its theories, or contradictions in the world, and the resolving of these inconsistencies or explanations of the contradictions is either learning or innovation, depending upon whether it had been done before or not. The resolving of the inconsistencies has been dealt with above, but it is worth noting that the new pattern generated could be vastly different to that before, i.e. a new theory developed. A point worth noting is that an idea or event needs forcing into the consciousness. Consider a word, that was explained for the first time a short while ago, which seems to be on every page that is subsequently read. It is unlikely that it is suddenly more frequently used, the most likely possibility is that the reader was never aware of it before. In the model postulated there are two forces acting on the cork, one towards the centre of the bowl due to the action of the large magnet, and the other due to the other corks acting outwards. It is possible to imagine a situation where an additional force would be required to push the new cork towards the centre, to overcome a net outward force when, for instance, there are a large number of corks around the centre. This would be equivalent to an apparently complete view of the world, e.g. a Kuhnian paradigm. Having been "pushed" into the centre it is possible that reorientation of the corks takes place, so that the corks find a new equilibrium position. If the re-orientation is large, a revolution could then be said to have taken place.

1.3. Irreversibility

A reversible process is one that is performed in such a way that, at the completion of the process, both the system and the local environment may be restored to their initial states without producing any change in the rest of the universe. Any other process is irreversible. (**ZEMANSKY**, 1957).

As an example consider an ideal gas expanding into a vacuum - free expansion. During a free expansion no interactions take place with other systems, and hence there are no local surroundings. The only effect produced is a change of state of an ideal gas from a volume V_i and temperature θ to a larger volume, V_f, at the same temperature, θ. To restore the gas to its initial state it would have to be compressed isothermally to the volume V_i. If the compression were performed quasi-statically and there were no friction between the piston and cylinder, an amount of work, W, would have to be done by some outside mechanical device and an equal amount of heat would have to flow out of the gas into a reservoir at the temperature θ. If the mechanical device and the reservoir are to be left unchanged, the heat would have to be extracted from the reservoir and converted completely into work. Since this last step is impossible, by the laws of thermodynamics, the process is irreversible.

A second example would be that of biological evolution. For this process to be reversible the work needed to restore the environment to its original condition would have to come from the energy stored in all the life forms. However, not all the energy used by the life processes is used for building up the energy storing structures.

Both the tendency to move to more order and the tendency to move to more chaos have the property that they appear to go only in one direction. They are made up of events that cannot be undone. However, they both derive from processes which do not have any preferred direction.

It is possible to describe all phenomena in terms of the interaction of elementary particles; if the laws that govern these interactions do not distinguish between the past and the future, what is the source of the irreversibility observed in the macroscopic world? It is not quite correct to say that these laws are time-symmetric. There is evidence that a temporal asymmetry exists at the level of sub-atomic particles in the decay of the neutral K mesons. Under certain conditions it can decay in a mode that is usually interpreted in terms of time reversal asymmetry. This apparent violation is observed less than 1% of the time, moreover K mesons are found only in experiments in high energy physics, they are not constituents of ordinary matter and they do not take part in the processes under consideration. (See GAL-OR, 1974).

Along with the physical laws, there are the constraints imposed on those laws by the environment to be taken into account (LAYZER, 1975). Laws describe the regularities or invarients in nature but they have to be applied to a physical system. However, the final state of a system is determined by both the initial conditions of the system and the laws of nature. As an example consider the motion of the planets in the solar system. Knowing Newton's laws of gravitation and the positions and the velocities of the planets at a given moment, it is possible to calculate past and future positions of the planets. Newton's laws explain why the planets obey Kepler's laws but they do not explain why the orbits of the planets are very nearly circular, why the orbital planes nearly coincide, or why the planets revolve around the sun in the same direction. These last facts arise from the conditions that existed when the solar system was formed. If a theory of planetary formation was available this would explain these regularities but it could only give a probable set of initial conditions from which the solar system could have evolved. The new theory itself would require particular initial conditions, which in turn would exhibit statistical regularities inviting a higher order theory. Thus, the uncertainty about actual states extends backward as well as forward in time.

Another definition of reversibility is possible. Consider a bottle of perfume which, for example, is left open in a room where the air is perfectly still, after a little while the perfume can be smelt by someone some distance away; molecules have escaped from the bulk liquid and made their way across the room. Eventually the whole of the perfume will evaporate and its molecules will be distributed evenly throughout the room. If a film was made showing microscopic detail so that the motions of the perfume molecules can be seen, individual molecules would be observed making their ways from the bottle and slowly across the room. If such a film was shown in reverse, the molecules would be seen converging on the bottle from all parts of the room. In both cases, the film being run in the correct direction and in reverse, the trajectories of the molecules would be indistinguishable, but it would still be possible to tell when the film is being shown in reverse. The initial conditions in the reversed film are exceedingly rare, each of the molecules is on a trajectory that will bring it back to a small volume of the room (the bottle) and once there will keep it there. This process is considered irreversible both from the standpoint of the second law of thermodynamics and from common experience.

If an optical system is considered from the point of view of the principle of reciprocity, it would appear that it would not matter if a film of the light ray paths was reversed. This would be true if the optical system were a simple one, producing a real image, the image and object could be interchanged. However, if the image is a virtual image, there is no image to be interchanged with the object. What emerges from a microscope or a telescope is a complex wavefront which the eye interprets as coming from an object at infinity. Here the knowledge of the use of the instrument would enable the observer to tell whether the film was reversed or not. A similar example is holography.

At this point it is worth asking the question whether a film of a control process could be reversed without the viewer knowing it? A film of a homostatic type of controller with random variations would be the same if run forward or backward . A film of a servo type of controller would show a period of control at one setting followed by a period of control at another. Stewart (1976) has suggested that this would be true no matter which way the film was run. However, both types of controller would be taking energy from the environment and so, by the strict thermodynamic definition, they would be irreversible. It is arguable that as cybernetics is concerned with information, and not energy, the thermodynamic definition is not relevant. When considering information in a system we assume that there is sufficient energy in the system and that the supply of that energy is such that any increase in entropy is radiated into another system; the system under consideration is in a steady state condition, as opposed to a system trying to reach a thermodynamic equilibrium state.

1.4. Microscopic and Macroscopic Information.

In order to find a solution to the problem of the direction of time Layzer (1967,1975) introduced the concepts of microscopic and macroscopic information. As time goes on macroscopic information is converted into microscopic information. Consider a drop of ink in water. Both the water and the ink are assumed to be incompressible fluids, i.e. are fluids not composed of discrete molecules but stoic fluids, that is, fluids all the way down the scale of size. The drop of ink sends out filaments that become thinner as they spread out, streamers eventually penetrate to every part of the water. The drop never separates into a multiplicity of droplets, and although its surface area increases without limit, its volume remains constant. The constant volume of the drop represents the deterministic conservation of the initial uncertainty, and its increasing surface area represents the stochastic increase of the uncertainty. This is known as the Liouville theorem. Thus, though the macroscopic order is destroyed it is still reflected in the microscopic order of the system. Even if, after a period of time, the resultant mixture looks as if the ink is completely distributed throughout the water, a microscopic cell of the liquid will contain ink and water in the same ratio as the original volumes of ink and water. As there are no isolated systems, apart from the universe itself, this microscopic order can itself be destroyed by random pertubations in other systems affecting the system under consideration.

The question is now, can macroscopic information be generated? Layzer argues that given suitable initial conditions it can. If, for instance, the universe was expanding (or contracting) at a rate faster than the rate of the processes bringing about thermal equilibrium, local departures from thermal equilibrium would occur given, only, that the universe was initially in thermal equilibrium, or, which amounts to the same thing, initially it contained no information. This means that such a universe is constantly generating order as it evolves, hence even a

Laplacian demon ("An intelligence that, at a given instance was acquainted with all the forces by which nature was animated and with the state of the bodies of which it is composed, would - if it were vast enough to submit these data to analysis - embrace in the same formula the movements of the largest bodies in the universe and those of the lightest atoms: nothing would be uncertain for such an intelligence, and the future, like the past would be present to its eyes") cannot predict accurately the future. If Layzer's theories are correct, even the universe itself - the ultimate system - never contains enough information to completely specify its future states.

Gold pointed out in the discussion to Layzer's 1967 paper the "Question about information is the famous geneticist's problem. Either the information content required to construct a human is entirely in the genes, or else the information content of the genes is much less than the required amount. The question is essentially about how the information should be defined. It is not clear to me (Gold) whether we should define the quality of information in such a way that it appears to grow spontaneously, or whether we should define it so that the content of the information is conserved".

It is not universally accepted, however, that entropy can be interpreted in terms of disorder. Medawar (1967) stated that order, or organisation as the boilogists understood it, meant complex regularity, with the extra connotation of stability. (By regularity it was not understood symmetry or periodicity, but rather tidiness or regulation, a state of affairs in which each element has its proper place). Order of this kind was by no means confined to the living world; it was the orderliness of a crystal, of a molecule, or in general of the solid state. But an increase of complex regularity could be accompanied by a decline of free energy, for example in the combination between gaseous hydrogen and oxygen to form molecules of water, which were more highly organised in the biological meaning of the word than the parent molecules; or again, in the phenomena of polymerization and crystallisation. In all such cases an increase in the degree of "organisation" was accompanied by an <u>increase</u> of entropy -- the opposite to what would be expected if the biological and thermodynamical order were the same. Willard Gibbs said that entropy was "mixedupness", biological order is not, or not merely, unmixedupness.

1.5. Purpose

The laws of thermodynamics were formulated for the steam engine of the nineteenth century, but we are interested in "living" machines. In this section we look to see if living machines vary from steam engines and if they do, whether the laws of thermodynamics are still relevant.

The chief characteristics of living systems are their invariance, their goal seeking behaviour and their ability to reproduce themselves. The first two are of interest here. There is a limit to this invariance, for if these systems were totally invariant there would be no evolution. In the case of biological systems, however, it is often more appropriate that the second law should be replaced by a postulate saying that such systems are homeostatic. By this it is meant that while an organism lives it strives to keep its parameters within certain limits. This can be extended to a mythical biosphere within which life, as a whole, keeps all the parameters within the limits necessary to maintain life. This can be considered as the opposite of entropy - there is a building up of more and more complex structures.

The other interesting property of living systems is their teleological nature, or their purpose structures. As Grey Walter (1969) put it " ... another aspect of cybernetics that often irritates conservative scientists (is) the implication of teleology. After all, the term means 'steermanship' and a steersman must have a course to steer and preferably a destination. However exasperating, a cybernetic approach enforces consideration of the purpose of the system under study or design. In the case of the interaction between intrinsic rhythms and sensory responses in the brain, what are the likely functions of the elaborate filtering mechanisms identified by such analyses as those described above? This simple question can be answered only by considering the specific functions of the eye and brain as a visual recognition system. Thus, the cybernetician by asking 'What is it for?', forces the experimentalist to decide 'What does it actually do?'".

Some writers (e.g. MONOD, 1972) have suggested that this type of description is merely linguistic, and it does not represent the state of affairs in the real world; if it is more than words it can be argued that there is a means of constructing a rational system of ethics. However, people like Monod believe that evolution is an Ashbian type homeostat that responds to perturbations in the environment in a strictly causal manner, that is, in accordance with the second law of thermodynamics.

The most important concept in cybernetics, as it is in system analysis, is that of purpose. As we have already said, this concept is anathema to physical scientists because it seems to imply that the human attribute of intentionality is being imposed on the inanimate world. Biologists, however, are prepared to talk about purposes of various organs, meaning the function of a particular organ. Thus the purpose of the heart is to pump blood.

Usual scientific explanations are of the causal kind; they take the form 'p because q'. Take the explanation of the event that the volume of a given mass of gas is halved, the usual explanation is that either the temperature of the gas has been halved or the pressure of the gas has been doubled. Thus it appears that this explanation is saying that the increase in pressure causes the decrease in volume. However, a different interpretation has been put on this explanation (HEMPEL, 1966). Using the same example as before, Boyle found that every time he increased the pressure the volume decreased, from which he developed a general law which purported to apply universally — Boyle extended his results to cover gases in general. The general form of a universal law can be expressed as 'when A occurs, B will also occur'; this enables a form of scientific explanation to be constructed. The following type of argument can be advanced:

(1) PV = constant

(2) the volume of the gas has been halved

(3) therefore, the pressure of the gas has been doubled.

This usually is expressed in shorthand, as it were, as the volume of the gas has been halved because the pressure on it has doubled. The law here has been implicitly assumed. Can this form of analysis be applied to teleological explanations?

Teleological explanations differ from causal explanations in that the event to be explained (referred to as the explicandum by some writers, e.g. BRAITHWAITE, 1953; HEMPEL, 1966), is explained in causal explanations, in terms of a cause which either precedes or is simultaneous with it—in a teleological explanation the explicandum is explained as being causally related either to a particular goal in the future or to a biological end which is as much in the future as in the present or past.

Braithwaite (1953) has argued that a fundamental property of a goal directed behaviour was the attainment of a goal under varying conditions. This plasticity enabled an organism, for instance, to reach a certain goal under different circumstances by using other forms of behaviour which made use of different causal chains. He then defined variancy, ϕ, as the range of circumstances under which the system attains the goal, and the class of those sets of field - conditions likely to occur as ψ.

Knowledge of the variancy, ϕ, could be obtained in two ways. It could either be obtained by deduction from a knowledge of the relevant causal laws, or it could be inferred inductively from a knowledge of the sets of field-conditions under which similar causal chains had attained their goals in the past. Braithwaite pointed out that there were two interesting sub-cases of the first case in which deliberate steps were taken to make sure that ψ is included in the variancy, ϕ . The first was the case where ϕ was small, but steps were taken to make sure that ψ was smaller still, e.g. a demonstration experiment. The second sub-case was that in which ψ was large, but ϕ was arranged to be larger still, e.g. a homeostat. When the variance was obtained from deduction from relevant causal laws, a teleological explanation of an event in terms of its goal-directedness was usually considered valueless.

The situation was entirely different if the knowledge or "reasonable" belief about the variancy had been derived either directly by induction from previous experience of similar goal-attaining behaviour, or indirectly by deduction from general teleological propositions which had themselves been established by induction from previous experience. It was when knowledge of the relevant variancy had been obtained independently of any knowledge of the causal laws concerned that a teleological explanation was valuable. Braithwaite also pointed out that in all cases of teleological explanation, inductive references occur at two stages of the argument. One stage was in the inference of the variancy and the other was the inference that the set of relevant conditions that will in fact occur in the future will fall within the variancy. Either of these inferences might be the source of error in any prediction based on such a system.

Braithwaite further stated that the special philosophical difficulty about teleological explanations of particular events, namely that in them the present appeared to be determined by the future, could also arise in the case of non-teleological laws considered as laws of nature without regard to their applications to yield particular explanations. Many non-teleological laws of nature, e.g. Newton's laws of mechanics, were symmetrical with respect to the earlier and later times occuring in the laws; they stated that the present was determined by the future just as much as it was determined by the past. Nor did teleological laws in general differ from non-teleological ones in having a time interval between the two related events - many non-teleological laws were about what happens during a period of time taken as a whole, e.g. the law of Least Action. The difference between the two types of law seemed to consist simply in the way in which the related variancy was discovered.

Braithwaite has compared the teleological law with another type of law found in psychology and biology, which shares with the teleological laws the characteristics that there is an interval of time between the determining and the determined event, and that these laws hold under a wide variety of conditions which have been discovered inductively and not deductively, what Bertrand Russell (1921) refers to as the "mnemic laws". The simplest example of such a law was that of memory recall, in which a present memory-image was determined (or partially determined) by the occurrence in the rememberer of an experience of which the present memory-image is an image. Another one would have been the Mendelian laws of heredity. In all the mnemic laws an earlier event was said to determine a later event without the intervening causal chain being specified or indeed known. Braithwaite goes on to state that if there was postulated a type of causation (which Russell called the "ultimate mnemic causation") in which a past event directly determined a future event without there being any intermediate causal chain, he would have agreed with Russell, that this would have been alien to usual ways of thinking. The causal chain type of argument for Braithwaite was represented by the search for such entities as genes and memory engrams.

If all teleological and mnemic laws (referred to by Braithwaite as "biotic laws") are ultimately reducible to causal chain type explanations, have they any value? Braithwaite thinks they have because the function of a scientific law was to organise empirical knowledge to give both intellectual satisfaction and power to predict the unknown. From this point of view, he argued that any general hypothesis whose consequences were confirmed by experience was a valuable intellectual device, even if it was later subsumed under a more general hypothesis in a more widely applicable deductive system, or the facts which it explained might have been explicable by a quite different hypothesis in another deductive system.

At this point it is as well to examine the notion of causality. At the beginning of this section the proposition that casual explanations were simply a shorthand way of expressing a syllogism was put forward. This sort of exposition does not, however, explain why one event should be considered as a cause and another an effect. Consider the example given, there is a mass of gas which, if I double the pressure on it, its volume will be halved - it will be reduced in volume in accordance with the law PV = constant until its internal pressure equals the external pressure it experiences. If, however, I reduce the volume to a half, its pressure may not increase - I could simply allow some of the gas to escape.

Therefore, we have an asymmetrical situation - an event A always leads to an event B, whereas an event B does not always lead to an event A. Thus if I wish to obtain event B, I will arrange for event A to occur, and to obtain event A I will arrange for an event that always leads to A, and so on. It then becomes natural to talk about an event causing another event (cause and effect). This argument can be further extended as in Newtonian physics where the gas was pictured as being made up of a number of hard, billiard-ball molecules which were constantly in motion. Momentum was transferred to the walls of the container by the molecules colliding with the walls, and the increase in pressure was due to the fact that the molecules hit the wall more often as the distance between the walls diminished. Thus the spatio-temporal distance between events is smaller as more and more refined explanations are invented (or discovered). Ultimately it is believed there will be found a continuous spatio-temporal connection between the two events - a spatio-temporally continuous causal chain.

This idea, that ultimately there can be an explanation that can provide a continuous causal chain between events, deserves to be looked at more closely. To argue that no such explanation would be theoretically impossible because all observations involve uncertainty (let alone Heisenberg) is to miss the point, as I see it, because the explanations go beyond the observed - they are constructions of reality in our minds.

The question is whether the logic of the human mind accurately reflects the nature of reality; or are the deductive systems used to manipulate scientific models purely constructs of the mind - to put it in terms of Spencer Brown (1969), did the universe give rise to a distinction that enabled it (the universe) to observe itself. If this were so we would be talking about a universe based on logical rather than mechanistic, or causal, relations. For example, consider gravitation. Gravitation is a force which acts at a distance but the nature of this action has not been satisfactorily explained; there is at first glance no spatio-temporal link between two bodies which are experiencing a mutual attraction. This leads to explanations involving such things as gravitrons and gravity waves, which in turn leads on to considerations such as; does a body radiating itself lose mass; how do these particles and waves interact with other bodies to produce attraction, and so on. Or, alternatively, the concept of gravity can be considered as a postulate within an axiomatic system governed by certain manipulative rules, as Newton and later Einstein did. If the last course is followed, care has to be taken not to confuse logical priority with chronological priority. Thus it is equally valuable, or valueless, to say that the volume of the gas has halved because the pressure on it has increased, as to say that swallows migrate to ensure the continuation of the species.

The trouble is that there are no criteria to say which approach is valid when studying a given system. It is considered inappropriate to talk about bodies seeking their true position in the centre of the earth to explain gravity, as Aristotle did.

It may well be that space and time can be considered as quantised, so that reality can be pictured as consisting of pigeon holes, the macro changes in the universe being explained in terms of micro movements from one state to another governed by simple transistional rules. This, of course, does not explain why there should be any change. This universe could be described in terms of Von Neumann's cellular automata (1966).

A CYBERNETIC APPROACH TO PREDICTION

2.1. Introduction

Chapter 1 investigated the traditional methods of using machine-like systems to predict future states of a system by means of a theoreotical model. In chapter 1 it was argued that 'problems of choosing adequate criteria arise when the machine is expected to change or adapt its model; problems of a logical nature which have been pointed out by philosophers of science from Hume onwards. To summarize the last chapter, the change from one model, or theory, to another can be considered as rational, in the sense that there are always reasons for the change, but those reasons vary from one case to another, making the process irrational. The search for suitable criteria is like the search of the rational philosophers for the self-evident truth upon which they could build the true system of philosophy. Another approach is possible - that of negative feedback, to quote Medawar (1967), "The regulation and control of hypotheses is more usefully described as a cybernetic than as a biological process: the adjustment and reformulation of hypotheses through an examination of their deductive consequences is simply another setting for the ubiquitous phenomenon of negative feedback".

This approach suggests that the reasons for the acceptance of a particular theory as opposed to another is due to the dynamic interrelationship between the rational being and its environment. This makes the analysis of the behaviour on the rational being side of the equation one of psychology rather than syllogistic, or deductive, logic. There is, of course, no reason why psychology should not be equated with logic, but it would no longer be traditional, or syllogistic, logic. Traditional, or syllogistic, logic generates valid statements from premises by means of syllogisms - deductive reasoning. Obviously, the value of a conclusion in this system depends on the value of the premises, the most valid of which were deduced from a syllogism whose premises were deduced from a previous syllogism whose premises were ....; an infinite regress. Another way of deriving premises, on which to carry out logical operations, is empirically. It has been often argued in the past that empirically derived premises do not have the certainty that deductively derived premises have. Observation can never be complete because of the limitations of the senses, but this applies equally to reasoning faculties. Logic is a function of the structure of our reasoning faculties, just as observation is a function of the structure of our senses. The study of these reasoning structures is psychology, therefore the terms "psychology" and "logic" are essentially the same. According to this "reasoning", logic is a function of the structure of the mind, and thus its study cannot be divorced from psychology.

Psychology as used in this sense is more than a study of the mind, it is a study of the whole organism and its relationship with its environment. The terms logical necessity and contingency, now, take on different meanings. It can be argued, for example, that all the attributes of homo sapiens are necessary, in the sense that they all contribute to the homo sapiens way of looking at the world; they all contribute to man's rationality (MERLEAU-PONTY, 1962). Man's understanding of the world depends as much on the fact that his thumb is in opposition to the rest of his fingers as to the size of his brain. It is contingent in the sense that there is no certainty that any particular individual will reach his full potentiality. In the same way the purpose structures generated by a living organism are a result of the organism as a whole — any ultimate purpose in the universe is a result of the universe as a whole. This analysis gives us a perspective of the universe that is different from that of the thermodynamicist with his picture of increasing entropy, but more like that of a biologist's perspective of a living organism. This is not to say that the concept of entropy is not important, but that it misses out any considerations of interaction between parts of the system. This interaction is important in biology where, in its simplest form it is known as negative feedback, and in its more complex form homeostasis. Thus, though in the universe there is an increase in entropy which leads to change, there are at the same time interactions between particles that bring about other structures by "chance", which are stable because their potential energy is at a minima.

2.2. Axioms of Cybernetics

Beer (1974) defined cybernetics as the "science of effective organisation", this implies that in cybernetics we are studying systems that are organised to achieve a given objective, or purpose. The first thing to do is to try to define a system. We can consider as a system, a collection of particles, bodies or entities that interact with each other. We, as cyberneticians, are not necessarily interested in the nature of these interactions – that is for physicists, psychologists, sociologists and the like. The ultimate system is the universe, and while it is true that every particle in the universe affects every other one through electrical, magnetic and gravitational forces, these are all inverse square law forces, so that the effect of particles a long way off is negligible and can be ignored with little loss of accuracy. Let us consider a system separated from the rest of the universe by adiabatic walls — that system will obey the first law of thermodynamics:

> If a system is caused to change from an initial state to a final state by adiabatic means only, the work done is the same for all adiabatic paths connecting the two states:
>
> $$Q = U_f - U_i + W \quad (= 0 \text{ for adiabatic system}).$$

This sort of quantity, i.e. one that is found to depend only on the initial and final states and not on the path connecting them, is found in various branches of physics. In mechanics, for instance, when an object is moved from a point i in a gravitational field to another point f in the absence of friction the work done depends only on the position of the two points, and not on the path through which the body was moved. From this it was concluded that there exists a function of the space co-ordinates of the body whose final value minus its initial value equals the work done. This function is known as the potential energy function. Similarly, the work done in moving a quantity of electricity from one point in an electric field to another is also independent of the path and is therefore expressible as the value of a function (the electric potential function) at the final state minus its value at the initial state. It therefore follows from the first law of thermodynamics that there exists a function of the cordinates of a thermodynamic system whose value at the final state minus its value at the initial state is equal to the adiabatic work in going from one state to the other. This function is known as the internal-energy function. To be of interest in cybernetics, we merely have to broaden the scope of the law to cover systems in other spheres such as psychology, sociology, politics and so on. Thus, one could imagine describing the obtaining of a given behavioral pattern by a test animal as requiring an input of energy over and above that needed by the animal for survival.

Systems, however, do not exist in adiabatic boxes in the real world. This means that energy can be exchanged between systems. Such systems, if left to themselves, would tend to find a minimum in their potential energy function. If a system has reached such a minimum it would require an input of energy to move it from this equilibrium position. If this pertubation is not very large the system would return to the equilibrium position; the energy being absorbed elsewhere in the system, e.g. heat, or re-radiated, e.g. light. Consider an atom in its ground state which is disturbed by an energetic electron, or a photon of light. The atom will become excited (if the energy is right) but after a time (relaxation time) it will return to its ground state, the excess potential energy being converted to light energy, which is radiated. If, however, the energy input is very large, the atom will become ionized and lose at least one of its electrons, just as a system can be destroyed if it receives too great an input of energy. The atom will now try to make up its complement of electrons from another atom. This fact, that all systems ultimately interact, has a bearing on objectivity. An observer, a system, must have some effect on what is observed, another system. This effect might be very slight, as in the case of astronomy, or very large, as in the case of political science. Stewart (1976) called the application of the first law of thermodynamics to cybernetics, the law of requisite power.

Requisite power is not enough to define a cybernetic system. A steam engine might well have sufficient power to pump out a mine working, but it would be unable to do so until a bucket, or a piston mechanism, was attached to it. To put it another way, the steam engine in its original state had only one possible mode of operation, that being to cause a beam to move in a see-saw manner. What is needed is for the machine to have variety, i.e. for the machine to be able to respond in an appropriate way to changes in its environment. When buckets are attached to its beam, the steam engine is able to carry out more kinds of jobs. Variety as defined by Beer (1974) "is the measure of complexity in a system as defined as the number of its possible states". It is obvious that if a control system is in an environment that has a large measure of variety, the system will require a large repertoire of actions in order to perform its function, i.e. it will have to have a large measure of variety. Ashby (1956a) formulated this concept in his law of requisite variety which he put in a graphical way as "only variety can destroy variety". It is also apparent that the mathematics of entropy, information and variety are closely related.

Ashby (1956a) defined a system as "not that thing there" in the real world, but a list of variables. The purpose of the scientist then was to find a set of variables that enabled a system to be considered as a single-valued transformation. Such a set of variables could be associated with a machine even though no real machine can, at any one time, be in more than one state, by considering a number of similar machines, or if the machine was unique, by considering the states that the system assumed at different points in time, or simply by fiat of the theoretician. Having, for one of these reasons, a set of states and one single-valued transformation, Ashby (1956a) went on to predict that as time progresses the variety in the set could not increase, and would usually diminish. This fact can be viewed from the point of view of the tendency of any system, left to itself, to run to some equilibrium. Further, even if the machine had inputs, not only does the system of which it was part reduce its total variety but the variety of the transducer is also reduced. This Ashby (1956a) terms the "law of experience" which could be stated as "information put in by a change at a parameter tends to destroy and replace information about the system's initial state". The law of experience has obvious applications to education. In a similar way a machine "learns" to react to a given situation in one particular way, and not in any one of the possible ways that it could.

Variety, as we have said, is, at first sight, analogous to entropy. The most striking similarity between the two is in definition. Both can be defined in terms of the number of possible states of the system. However, if we consider a controller in an environment which is highly chaotic, i.e. has a large measure of variety and also a large entropy, then in order for the controller to keep whatever it is controlling within predetermined limits, it must have, itself, a large measure of variety. The controller, however, does not have a large measure of entropy, indeed if it did it would not be a very good controller, it, however, requires energy to carry out its function, and so by the second law of thermodynamics it is generating entropy. A second similarity is that both define a direction in time, but while entropy cannot decrease, variety cannot increase. This means that there is no problem with the direction of time if one considers it from the point of view of variety. Even in evolution there is a reduction of variety. As an animal evolves it becomes more specialized, a horse becomes a better and better runner but, because it has specialized in this manner, its responses to changes in its environment have become more limited. The organism with the most variety was the first "living" molecule which was able to respond to changes in its environment in, at least, the ways we can see around us. A third similarity is that both are statistical, and both the increase of entropy and the decrease of variety are long term. There can be short term reversals. Consider an ingot of metal, if this is made into an ornamental door stop its variety has been reduced. However, if this door stop is melted down its variety has been increased, though it is now only, at the most, the same as it was at the beginning.

Stewart (1976) has pointed out that requisite power and requisite variety were still not enough to define a cybernetic system. The system has to have a "desire" to perform the act, or the "awareness" of the possibilities of the situation. Up to now in the discussion all the motivation has come from a human operator. A human decided that he wanted the mine pumped out. To the Greeks this would not have been a problem - after all, did not base objects fall to the centre of the earth because they wanted to be there? It can be considered that all systems have the desire to minimize their potential energy. It then becomes possible to visualize using this "desire" to obtain a given end. By arranging that a thermostat achieves a minimum potential energy when the room is at a desired temperature, then both the designer and the thermostat have the same "desire" (STEWART, 1976). The thermostat can never "desire" more than its designer (STEWART, 1976). This, of course, leaves the problem as to how the designer obtained his "desire", except that it could be the sum of the desires of all his components.

As to why any system should have the desire to change its state, more will be said later, but though we said that the interaction with distant systems is very small, it has been calculated (BOREL, 1912) that the change in gravitation potential caused by displacing one gram of matter at the distance of the star Sirius would, in the course of 1μS, substantially alter the microscopic state of a volume of gas on earth.

2.3. Entropy, Information and Variety

Although in an isolated system energy is conserved, this energy may be sub-divided into two fractions; one of these is able to perform work and is called the free energy; the other is bound, or unavailable energy. The second law of thermodynamics states that the bound energy of an isolated system can only increase, the free energy only decrease. The degree of unavailable energy is given by the measure called entropy. For systems in which changes take place at a constant temperature - isothermal processes - the entropy is simply the total bound energy divided by the temperature of the system. If temperature changes are involved, the entropy change is defined as the sum of the changes in the quantity of heat divided by the temperature (which, for small changes, is virtually constant). Gross entropy changes are thus defined by the integration over a sequence of smaller ones:

$$S = \frac{Q}{T} \quad \text{or,} \quad S = \int \frac{dQ}{T}$$

where, S = entropy, Q = quantity of heat, T = temperature. 1

The maximum entropy of the system is obtained when all the free energy in the system is converted into heat, i.e. kinetic energy of the molecules. As these molecules are in motion, colliding with each other and the walls of the container, there will be a distribution of velocities (usually a Maxwell distribution) around a mean. This mean corresponds to the macroscopic quantity of temperature. The system will be in equilibrium i.e. if some molecules are accelerated so that they become faster, other molecules will become slower. What is more, the distribution of the velocities and numbers of molecules will be the same throughout the system. This means that there will be no temperature differences to provide any useful work. Viewed at the microscopic level, the system is known as a stochastic one, and so there is always a remote possibility of the molecules redistributing themselves in such a way that there is free energy available. If the universe was to run down to a condition of maximum entropy, the temperature would be about 3K. Given a long enough time, by random motion, it is possible that the molecules could rearrange themselves so that all the energy in the universe was available. The time spent in this condition would be very short before it again ran down to a state of maximum entropy, where it would remain for a long time. Thus, it is possible to define entropy in terms of the probability of the state occurring, or what amounts to the same thing, in terms of a measure of disorder. The greater the disorder the greater will be the spread of energy over the system, i.e. for high entropy nearly all the molecules will have an energy which is near the mean, rather than a few with large energies and a large number with small energies.

Boltzmann's measure of disorder states that if A_1, A_2, ...A_n are a complete set of alternative states, with the corresponding probabilities P_1, P_2, ...P_n, the entropy is given by the following expression:

$$H(p_1, P_2 \ldots\ldots P_n) = -\sum_{i}^{n} p_k \log p_k = \sum_{i}^{n} p_k \log\left(\frac{1}{p_k}\right)$$

where H is the entropy and the base of the logarithm is arbitrary. H is a minimum when one of the P_i equals 1 and the rest equal zero, and a maximum (and equal to log n) when all are equal to $\frac{1}{n}$.

There is, of course, an endless variety of measures of disorder. Boltzmann's measure has the property that the propositions of thermodynamics can be deduced, and in the deduced equations this measure of disorder corresponds, in the empirical equations of thermodynamics, precisely to the measure of entropy. The only difference is that the statistical measure of disorder is a dimensionless variable and must be multiplied by a dimensional constant, k (Boltzmann's constant).

To see how this is related to information, imagine a telegraphic system in which the receiver may exist in a large number of possible states, B_o

say, all of them having the same probability. When information is received, the number of possible states is reduced to B_1. We can take the logarithm of the ratio $\frac{B_o}{B_1}$ as a measure of the information I_1. Thus we have the equation:

$$I_1 = \text{const. } \ln \frac{B_o}{B_1}.$$

This can be compared with the relation between entropy and thermodynamic probability:

$$S = \text{const. } \ln B,$$

and if the two constants are considered to be equal, yields the result that

$$S_1 = S_o - I_1$$

where S_o = const. ln B_o is the initial entropy, and S_1 = const. ln B_1 is the final entropy with information I_1. Thus, the information corresponds to a negative in the final entropy of a physical system, or

Information = Negentropy (BRILLOUIN, 1956).

Hawkins (1964) has pointed out that since Shannon (1949), information theory had been extended to many areas in which the term "information" had no relevance except as a kind of metaphor. Even in the context of communication a transmission of meaningless nonsense was just as much information as an intelligible message. What was always involved in applications of the theory was some kind of physical coupling in virtue of which a duplication of pattern occurs.

Hawkins went on to state that we could eliminate the apparent inappropriateness of the term "information", not by changing the term, but merely by reversing linguistic history — by renovating an original broad meaning that had almost disappeared. The meaning of "information" in current colloquial English was a degenerate specialisation of the original in + formatic, - literally, the transference of form or, alternatively, form as transferred. The term was from medieval philosophy, and it was actively used in the intellectural context of efficient and final causation. A cause was not merely what was abstractly necessary, or sufficient, to an effect - a cause was what shapes, informs, the effect. This type of argument went back to Anaxagoras, in whose cosmology Cosmos was born of Chaos by the sorting action of the mind, and the Great Chain, the graded hierarchy of Being. It was reflected by Anselem of Canterbury (and echoed by Descartes and Spinoza) who said that the cause cannot be less perfect than the effect, so that every essence entails an antecedent and not less perfect existent - and "that than which nothing more perfect can be conceived, cannot exist in the mind alone". The underlying presupposition, from Anaxagoras to Spinoza, was the association of cause with reason, of the order of nature with the order of thought. In some important sense the tradition of the Great Chain was the prehistory of thermodynamics. Alternatively, it is possible to say that in the framework of twentieth-century categories "causality" in the old sense is a thermodynamical rather than a dynamical term (HAWKINS, 1964). To see how information is related to variety compare the above with a machine with a high measure of variety. This machine in its pristine state is, therefore, full of uncertainty - its content is chaos. Once the machine begins to operate, however, a degree of order is introduced, and this ordering begins to eliminate the ruling uncertainty. This information, thus, removes some of the variety (BEER, 1959). Finally, Wiener (1948) has written that information was information and not matter or energy. Information was usually a concept that was applied to patterns which were spread out or had to be read out in a series - a time series. Information could be measured in a formally similar way to negative entropy, but this did not make it negative entropy.

2.4. Regulation and Control

The next section comes from Ashby's "Introduction to Cybernetics" (1956a). It is possible to set up a table, for a machine with inputs (a transducer), showing the outcome if the machine reacted to an input, or disturbance, in a number of different ways.

e.g.

REGULATOR, R

		A	B	C
	1	b	a	c
DISTURBANCE,	2	a	c	b
D	3	c	b	a

This machine can be considered a regulator if it acts in such a way as to bring about a favourable outcome, say a. This, of course, says nothing about who or what decides what a favourable outcome is.

Regulation is said to occur when, in response to a set of disturbances, D, from outside the organism, that threaten to drive the essential variables, E, outside their proper range of values, a regulator acts in such a way as to transmit to the organism the disturbances in a form that no longer threatens to drive its essential variables outside their proper range. The values of E correspond to the outcomes of a table, T, similar to the one above. The table, T, is assumed to be given. It is the external world, or those parts of the organism that the regulator has to take for granted.

The general phenomenon of regulation can be interpreted in terms of communication. If R does nothing, i.e. keeps to one value, then the variety in D threatens to go through T to E, contrary to what is wanted. It may happen that T, without change by R, will block some of the variety, and occasionally this blocking may give sufficient constancy at E for survival. More commonly, a further suppression at E is necessary; it can be achieved, only by further variety at R. R can now be considered as transmitter.

The law of requisite variety can now be interpreted in terms of information theory as R's capacity as a regulator cannot exceed R's capacity as a communication channel. This can be compared with Shannon's theorem 10 (SHANNON, 1949) which says that if noise appears in the message, the amount of noise that can be removed by a correction channel is limited to the amount of information that can be carried by that channel. "Noise" corresponds to "disturbance", "correction channel" to "regulator R" and "message of entropy H" to a message of zero entropy, as it is constancy that is to be "transmitted". Thus the use of a regulator to achieve homeostasis and the use of a correction channel to suppress noise are homologous.

Another box, can be added to this sequence, whose function is to supply some control to the system. The decision of what outcome is to be the target is made by the controller, C, whom R must obey. The system now has two independent inputs, C and D. If R is a perfect regulator and C sets a as the target, then (through R's agency) E will take the value a, whatever value D may take. Thus a suitable regulator, R, taking information from both C and D, and interposed between C and T may be able to form, with T, a channel to E that transmits fully from C while transmitting nothing from D. The achievement of control may thus depend on the achievement of regulation. The two are, thus, intimately related.

The basic formulation of regulation discussed above assumed the following order of operation:

1) a particular disturbance threatens at D;
2) it acts on R, which transforms it to a response;
3) the two values, of D and R, act on T simultaneously to produce T's outcome;
4) the outcome is a state in E, or affects E.

Thus 3) supposes that if R is an actual material system, it performs all its work before T starts to move. It is assumed, in other words, that the regulator R moved at a higher order of speed than T.

This sequence does actually occur in many cases. When a cat approaches, the mouse may react so as to get to its hole before the cat's claws actually strike. The organism has reacted to the threat (at D) rather than the disaster itself (at E) and has thus forestalled the disaster. On the other hand, there are many important cases in which this anticipation is not possible - in which R's action cannot be completed before the outcome (at T) starts to be determined. In this case, regulation might be based on the effect of the disturbance on E - regulation by error.

From the point of view of communication, the new phenomena are easily related to the old. The difference is simply that now information from D to R (which must pass if the regulator R is to play any useful part whatever) comes through T, and the information available for regulatory purposes is whatever survives the coding imposed by its passage through T. Sometimes the information available to R is forced to take a longer route, so that R is affected only by the actual effect at E. This is the basic form of an "error - controlled servo-mechanism" or a "closed loop regulator", with its feedback from E to R. This type of regulator can never be perfect.

Finally, in this section we shall consider, briefly, a Markovian machine type regulator. This is one in whose states change with time, not by a single-valued transformation but by a matrix of transition probabilities. This machine is still capable of goal directed behaviour, but instead of moving in a determinate way to that goal it seems to reach in an haphazard way, or as Ashby puts it "a hunt and stick" way. Movement to a goal by the process of hunt and stick is homologous to the movement by a determinate trajectory, for both are the movement of the machine to a state of equilibrium. With caution, we can apply the same set of principles and arguments to both.

The progression of a single Markovian machine to a state of equilibrium is much less orderly than that of a determinate machine, so the Markovian type of machine is little used in the regulators in industry. Nevertheless, living organisms use this more general method freely, for a machine that uses it is, on the whole, much more easily constructed and maintained; for the same reasons it tends to be less upset by minor injuries. It is used in many simple regulation processes where speed and efficiency are not of importance. Such an example might be the use of flypaper to regulate the fly population. Once a fly lands on the flypaper it remains there, and so the number of free flies in the room is reduced.

2.5. Motivation

Up to now we have considered the action of a control system and discussed the limitations on such a system due to the finiteness of the system and hence its finite resources of power and information. Thus a homeostat cannot protect itself against the force of a hammer which is intent on smashing its internal workings; there is no possible way that it can restore itself after the attack because some of the parts have been removed from the field of homeostatic interaction with the other parts of the homeostat. Nor does it have enough information inputs to "see" the hammer coming, or put itself together after the attack. These limitations can be seen as a hierarchy, at the bottom of which are considerations of energy and power, and at the next level are considerations of information. Thus, in designing a control system incorporating a thermostat, the first consideration would be in arranging that the heating element, or cooling element, is able to reach the desired temperature in that particular environment. The boiler, in a central heating system, has to be physically able to heat a given volume of air, for example, so that despite the ambient temperature, and losses, the house temperature reaches a predetermined level. Given that the system is able to do this, it is possible to consider the actual control of the temperature. A system could be designed, for example, that could arrange for individual rooms to be kept at predetermined temperatures by the use of thermostats and valves that could cause certain radiators to be by-passed. This is now a problem in ensuring that enough information, data on the temperature of the rooms, is entering the system; it has been assumed that there is enough power in the system to provide the heat required, and operate the valves, etc. This had led Stewart (1976) to propose that there are three levels at which science operates. Suppose that a system has sufficient power and information to bring about a desired end, there is a higher level on this hierarchy that is of interest to cyberneticians.

It has been argued throughout the history of philosophy (e.g. Descartes) that the thing that differentiates man (and animals?) from the rest of nature is that he is capable of setting his goals and then striving for them. Descartes, for example, argued against the concept of gravity that Newton espoused – that this would lead to a teleological explanation of the Aristotlean type (see RÉE, 1974). He was led, because of this, to devise a complicated theory of vorticies to explain the motion of the planets. Descartes said (1912) "I used to think that gravity carried bodies towards the centre of the earth, as though it had some knowledge of this centre". Rée (1974) argued that, "Descartes assumed that the only things which could have aims or purposes were things that could think, and so he thought that teleological explanations could only be applied to the products of such beings", and, "that he concluded that their application to anything else involved a confusion of the mental and physical, and was nothing but a relic of the primitive magic which sees purely physical phenomena as the operations of thinking beings".

It is possible that Descartes was mistaken. It could be that to explain certain phenomena in terms of purpose might lead to simpler and more interesting explanations. For example, the action of a thermostat could be explained in terms of the action of a bimetal strip or some other mechanical device. Alternatively, the action of a thermostat could be explained in terms of keeping the temperature of a room constant – in terms of goal directed behaviour. The type of explanation depends on the purpose to which that explanation is to be put; there can be no non-arbitrary way of looking at nature, so we are free to employ the most useful type of explanation. However, an attempt can be made to postulate how inanimate matter are able to take part in goal-directed, or purposive, behaviour.

Purposive behaviour, especially as partaken in by human beings, usually takes the form of arranging events so that a desired result is brought about. The problem is, of course, that of an object desiring a particular result.

The object of physics is to reduce all physical phenomena to the interaction of a few fundamental characteristics common to all particles. Newtonian physics attempts to reduce all physical phenomena to considerations of mass, motion and the mutual attraction of massive bodies. Just as Newton postulated a force called gravity to explain this mutual attraction, Stewart (1976) has postulated that there was a property possessed by all particles, namely, "desire" or purpose. This, of course, does not explain what desire or purpose is any more than calling the phenomenon "gravity" explains it. Newton, however, did more, he made his "gravity" quantitive - a similar operation has to be carried out on desire, or purpose. It is interesting, in this connection, to mention Pascal's argument for the existence of God. His argument was to put forward the hypothesis that God exists, in the manner of a scientific hypothesis, and he proposed that this hypothesis be tested to see if it brought about the desired results; if it made the believer happier and so on.

If it is accepted that all particles possess this property even if it is in a very elementary form; it is possible to explain human behaviour as a favourable combination of these elementary desires, just as the sun radiates energy because it is more than a certain mass. Also if a system is built which has a small amount of desire, it is possible to use it to amplify desire, just as intelligence and power can be amplified. Desire as a level, however, differs from the levels of requisite , power and variety in that it is always an on-going process. An animal when it has satisfied one desire finds another unsatisfied and modifies its behaviour in order to satisfy the new desire.

2.5.1. Theories of Motivation

Prior to the eighteenth century it was generally held that man was able to exercise complete control over his actions. As a rational creature he had the power to direct, redirect or inhibit his passions at will. These ideas were bound up with the early philosophies relating to religion and morals. Man was seen as a pleasure-seeking, pain avoiding creature. Animals on the contrary, were activated by instincts - inborn mechanisms which give rise to fixed ways of satisfying animal needs.

McDougall (1908) used the arguments of Darwin to justify his "hormic" or "Instinct Theory" in which he postulated that man's actions, as well as those of the animals to which he was related, were the outcome of instincts - inate and unlearned tendencies to behave in specific ways in response to various biological and social needs. The idea that man was tied down to fixed patterns was heavily criticized and he modified his view by suggesting that man was endowed with "propensities" rather than animal instincts. Burt (1941) defined a propensity as a "complex inherited tendency, common to all members of a species, impelling each individual (a) to perceive and pay attention to certain objects and situations; (b) to become pleasurably or unpleasurably excited about those objects whenever they are perceived; (c) thereupon to act in a way likely in the long run to preserve the individual by so acting".

The main argument against the instinct theory was that human beings do not display stereotyped pattern of unlearned behaviour. The contrast in the behaviour of a bird feeding its young, or in the courtship rites of many species of birds and animals, with similar events in man indicates that human behaviour is not based on an instinctive drive. Work of social anthropologists (MEAD, 1935; BENEDICT, 1935) indicated that the behavioural patterns of aggression, acquisition and sex vary from tribe to tribe. Again, motives are so complex and overlaid with secondary and acquired desires that the theory of inherited tendencies becomes impossible to validate. Allport (1937) recognized this and coined the phrase "functional anatomy" to describe the acquisition of new motives derived from more fundamental motives, which ultimately become divorced from the latter, e.g. drug taking, professional attitudes, etc.

Lorenz and Tinbergen (LORENZ, 1967; TINBERGEN, 1951) have revived the concept of instinct as applied to man and contend that man, being a biological organism and subject to evolutionary development, is possessed of intuitive urges which if studied would give a sound scientific basis to human behaviour.

A second approach, variously referred to as Physiological or Behavioural Theories, has the central tenet that all actions have their roots in efforts to satisfy organic needs such as food, water, air, pain avoidance and body temperature maintenance for personal survival, and courtship, mating and parenthood for species survival. More complex behaviours at first sight seem far removed from the simple gratification of body needs; however, many followers of these theories believe that they also arise from the struggle for survival. Satisfaction of the basic or primary needs is brought about by primary drives (HULL, 1943). Acquired or secondary reinforcers appear as by products of basic needs.

Great play has been made of physiological states of disequilibrium when the body is deficient of basic need. When deficiencies occur, the body registers the imbalance through the agencies of blood and arousal systems in the brain (hypothalamus). Thus Hull equated psychological drive with physiological need by the process of homeostasis.

Freud's (1915) psychoanalytical theory went some way to bridging the instinctual views of McDougall and the physiological theories. He argued that there are two basic instincts (or "moving forces") of life and death. These originated from bodily needs. The life instincts included (a) sexual instincts (libido instincts) and (b) instincts required for life preservation and maintenance (ego instincts). The death instincts were never properly defined but are loosely incorporated as inner processes. The only one specifically defined by Freud was the aggressive instinct. He believed these instincts to be there at birth, a "cauldron" of instinctual energy referred to as the ld. The constraints placed on the expression of these basic desires by conscious effort on the part of the individuals or as a result of social pressures, chiefly parental influences, lead to repression of the desires. The "taming of the passions" of the Id was made possible by the Ego, such that many defence mechanisms replaced the immediate gratification of basic desires so that the motive energy is used in more socially acceptable ways. Exclusion from the conscious mind of less desirable solutions to instinctive cravings did not mean that they have disappeared altogether. Freud created the unconscious mind which contains the traces of unpleasant and repressed memories. Behaviour was hereafter influenced whenever similar circumstances to the original experiences occurred, but the individual was not aware of the source of his behaviour. The root cause of motives would only break through in special circumstances such as hypnosis, dreams, drugs or in a psychotherapeutic session when the defences were down.

The instinct, physiological and the earlier psychodynamic approaches to motivation, undervalued the influences of social pressures and patterns of culture into which a child was born and reared. Culture-pattern and Field theories have sprung into being over the past forty or so years in response to this omission (see HARLOW & ZIMMERMAN, 1959; also LEWIN, 1936).

2.5.2. Needs

Maslow (1943 and 1954) postulated a hierarchy of needs in the form of a pyramid. At the bottom are the physiological needs; then safety; then love; then self-esteem and the esteem of others; and at the summit "Self-actualization", the effort to realize the maximum fulfilment of all the potentialities and abilities, especially the creative abilities. These needs developed in turn as the child grew up, but the higher appeared and functioned only in so far as the lower needs were reasonably satisfied. The higher needs were not for the removal of deficits, or for producing relaxation of tension. Their expression in motivated behaviour was itself positive and pleasurable. It led to continued activity and the search for new and higher goals, though satisfaction might be more readily postponed than in the case of the lower needs. The latter remained below the level of consciousness as long as they were reasonably well satisfied, but could emerge and dominate behaviour in conditions of deprivation or frustration. Again, the need for safety was strongest in children, but it could also dominate the behaviour and emotions of adult neurotics, who had not developed the normal adult degree of security. However, maladjustment and imperfect adult development were more commonly produced by lack of love. Some people who have been unsatisfied in their need for love may seek satisfaction instead in obtaining esteem. Only the most mature and intelligent could reach the final stage of self-actualization, which was accompanied by the capacity to accept and depend on the self; to cease from identifying with others, to rely on one's own standards, to aspire towards the "ego-ideal" and to detach oneself from social demands and customs when desirable. However, it should be noted that the people who have reached this stage are relatively uncommon — Maslow was unable, in his studies, to discover more than a small number among his acquaintances. There is evidence to show that the majority of people are more ready to accept certain motives and characteristics of their personalities than others. However, the greater the degree of acceptance of self, the greater the willingness to accept other people and the problems they present.

Maslow also considered that, independent of his hierarchy of needs, there were motivational tendencies towards obtaining knowledge and understanding through exploratory behaviour. He did not discuss those important types of motivation, which lead towards independence and individual achievement; they could however be involved in the development of self-esteem, and were, therefore, transcended at the stage of self-actualization. Many conflicts in life arose from independence and achievement motivation — Maslow admits that, although reasonable satisfaction of the lower needs could be a pre-requisite for the attainment of self-actualization, nevertheless there must have been also the capacity to overcome frustration and conflict, but it must have been through realisation and acceptance, not through escape and avoidance. Thus self-actualization could not be attributed to individuals in whom an over-riding interest was joined with avoidance or repression of emotional difficulties and problems of social relationships. Rather in self-actualization there must be a harmonization of motivation relating to interests, personal achievement and involvement in human relationships.

2.6. Desire as a Nontransitive Relationship

Whenever a relation R that applies to xRy and yRz also applies to xRz, the relation is said to be transitive. Such relations would be "earlier than", "heavier than", "taller than", "inside   ", and so on. Nontransitive (or intransitive) relations would be of the form A is the father of B and B is the father of C, A is never the father of C. Another is found in the children's game in which, on the count of three, one either makes a fist to symbolise a "rock", extends two fingers for "scissors" or all fingers for "paper". Rock breaks scissors, scissors cut paper and paper covers rock. In this game the winning relation is intransitive.

Intransitivity occurs in a number of situations of interest. Consider an election in which the voters list their preferences in order. One-third of the electorate prefer candidates A, B and C in the order ABC. Another third rank them BCA and the rest CAB.

	RANK ORDER		
	1	2	3
voters			
$\frac{1}{3}$	A	B	C
$\frac{1}{3}$	B	C	A
$\frac{1}{3}$	C	A	B

From this matrix it can be seen that two-thirds of the voters prefer A to B, two-thirds prefer B to C and two-thirds prefer C to A. If A was to run against B, A would win. If B ran against C, B would win. If C ran against A, C would win. If A, B and C represented not men, but parliamentary motions, then the party in power could easily arrange for a desired result by its choice of which paired proposals to put up first for a vote. This situation can arise when a decision has to be made between two alternatives from a set of three or more.

Suppose A, B and C stand for apple pie, blackcurrant pie and cherry pie. A certain restaurant offers only two of them at any given meal. The matrix now shows how a customer ranks the pies with respect to three criteria, say, taste, freshness and size of portion. If equal weight is given to each of the criteria then it is perfectly rational for the customer to prefer apply pie to blackcurrant pie, blackcurrant to cherry, and cherry to apple. It can be argued that such nontransitive orderings occur quite commonly in daily life. (See McCULLOCH, 1945; 1956). This has further been developed by Stewart (1976).

It would seem possible to rationalise the logic of scientific discovery along these lines. Suppose we used the criteria of elegance, applicability and accuracy. To see that accuracy could be only one of three criteria consider an example given by Thom (1975). Consider the experimental results from the study of some phenonema which gives a graph with equation $y = g(x)$. To explain this the theorist has available two theories – these theories give graphs $g_1(x)$ and $g_2(x)$, respectively. Neither of these graphs fits the graph $y = g(x)$ well – the graph $g_1(x)$ fits better quantitatively in the sense that over the interval considered, $\int |g-g_1|$ is smaller than $\int |g - g_2|$, but the graph g_2 has the same shape and appearance as g. It could be more rational to accept the theory giving g_2 on the grounds that it was more elegant (simple), and applicable over a greater range, even if it was not as accurate.

Chapter 3

MODELS OF INTELLIGENCE

3.1. Introduction

Various cybernetic machines have been built to demonstrate different aspects of intelligent behaviour, but it is important to note that these machines act not upon the external world but on an internal representation of it and so they must be considered as demonstrating aspects of rational behaviour rather than intelligent behaviour. However, for the purpose of this chapter it will be assumed that an adequate representation can be generated in some manner and so the two terms are synonymous. In the Turing machine, for instance, the representation was in the form of a paper tape divided into squares within which were written symbols which the machine read. This paper tape could be considered as the external environment for the machine, but as such was a highly artificial one unless the symbols are somehow written by the environment, in which case it becomes an internal representation of that environment. The input of such a machine could consist of a multiple number of tapes, or alternatively a number of parallel inputs, each capable of two or more values, depending on the external scene, as in Uttley's machines.

One striking common feature of this type of machine is that the more closely it exhibits intelligent behaviour the more it shows a dual nature, i.e. it employs both digital and analogue data processing methods. These machines usually work in time by performing their logical calculations at discrete points, i.e. t_1, t_2 ...... and so on. The period between two adjacent time points depends on the speed of the tape in the Turing machine, the time needed for classification in Uttley's machine, and the sampling periods in Gabor's filter. In the human this time period is determined by the refractory period of the nerve fibre.

3.2 Models of Nervous Activity

In 1949 Hodgkin, Huxley and Katz postulated that the nerve membrane became selectively permeable to Na^+ ions during the initial large positive "spike" of the action potential. They reached their conclusion from the study of the giant axon of the squid (HODGKIN, HUXLEY AND KATZ, 1949). When the nerve fibre was resting a potential was generated across the membrane, which was made possible because the membrane was a semi-permeable one, i.e. the diffusion of ions from a solution on one side of the membrane to a solution of the other side was possible provided that the molecule sizes involved were not too large. The interior of a nerve fibre consisted of a solution of postasium in the form of K^+ ions and a protein ion, with a negative charge. The exterior of the fibre was bathed in a solution of sodium (Na^+) and chlorine (Cl^-) ions. As the protein ion was much larger than the other ions it was unable to cross the semi-permeable membrane barrier, as the others did, and this resulted in a distortion of the redistribution of the other ions. If the flow of ions was purely random the situation would reach an equilibrium when the concentrations of each type of ion, which were capable of passing through the membrane, were the same on both sides of the membrane, and hence there would be a large net negative charge on the inside of the membrane, due to the protein ion. In point of fact the electrical forces generated by this movement caused the concentration of ions not to be equalized on both sides of the membrane, there being a larger concentration of Cl^- on the outside of the fibre and K^+ inside, and the bulk of the two solutions were electrically neutral. The layers immediately adjacent to the membrane on the inside, however, would contain more of the negative ions and the layers immediately adjacent to the outside of the membrane would contain more positive ions. This resulted in a small potential across the membrane.

This potential could be calculated from the following equation, which was referred to as the Nernst equation:

$$V = K \log \frac{C_e}{C_i}$$

where C_e was the concentration of a particular ion on the outside of the fibre and C_i its concentration in the interior of the fibre.

Calculated results for measured concentration of ions in a nerve fibre are tabulated below.

Ion	Membrane potential in mV	
	Predicted by Nernst eqn.	Actual
K^+	- 75	-70
Cl^-	- 75	-70
Na^+	+ 50	-70

These results lead to the conclusion that the membrane was not permeable to Na^+ ions, certainly not in the resting state. The +50mV, however, tied in well with the potential when the nerve fibre was carrying a signal. The nature of the barrier to Na^+ ions is not well understood, but measurements using radioactive sodium do indicate that some Na^+ ions leak into the resting nerve membrane and are subsequently extruded by a "sodium pump".

The potential across the membrane can be written as

$$V = \frac{g_{Na} V_{Na} + g_K V_K}{g_{Na} + g_K}$$

where g_{Na}, g_K are the membrane conductances to the sodium and potassium ions respectively and V_{Na} and V_k are the potentials generated by the differences in concentrations of the various ions.

Caldwell and Keynes (1957) have shown that the removal of Na^+ ions is an active process requiring metabolic activity. However, the actual mechanism of such a process has still to be demonstrated.

3.2.1 Neuristors

Crane (1962) described a novel device and system which he termed a neuristor. The disadvantage of electronic devices was that as micro-electronic devices became smaller, the linking wires would have appreciable resistance leading to large attenuation of signals. To overcome this an active wire was sought, similar to a chemical fuse or a nerve fibre. Such a device would have the following characteristics:

a) Symmetry They would be longitudinally symmetric. In the paper it was demonstrated that complete logic capability could be achieved using symmetric lines only. (No advantage was obtained by using asymmetric lines that could sustain propagation in only one direction.)

b) Form of Propagating Signal The velocity and form of the signal would depend only on the properties of the line itself.

c) Refractoriness Each portion of the line would become refractory for some period after the passage of the discharge. This meant that some minimum spacing must exist between pulses propagating in the same direction along the line.

d) Destructive Collision A basic property of neuristor lines would be that two discharges propagated towards each other are annihilated upon collision. At the instant of collision the line was refractory on both sides of the collision point, thus neither signal could continue to propagate.

c) Reflectionless Collisions Signal reflections would occur at discontinuities in linear transmission lines. A neuristor line was inherently free of such reflections of the discharge. This property of reflectionless collisions (whether with another pulse or at discontinuities in a line) was very important in the logical design of neuristor networks.

A realization of such a device is shown in Fig. 3.1. A trigger signal sufficient to operate the relay was applied to the relay, causing the contacts to close and thus the voltage in the line to rise to kV_T. The refractory period was due to the finite time needed to charge the capacitor. Another such device would be a fibre optic laser. The signal can only be propagated through a laser when the electron population of the material has the right energy distribution (the inverted population distribution), which is usually obtained by electrical or chemical means. (See KAPANY 1967)

This concept allows for a memory system external to the nerve cell. The amplitude signal will depend on the value of kV_T, i.e. the concentration of Na^+ ions in the fluid around the nerve fibre, which will determine the likelihood of the signal passing the next synapse. Also, information can be stored in rings, provided the length of the ring is large compared with its refractory width. To erase a signal from such a memory it would only be necessary to inject a signal travelling in the opposite direction. Such neuristor lines can be joined together in ways that allow the signal travelling down one line to trigger all the others, or other ways so that a signal in one line will inhibit the transmission of a signal in the others. These functions allow the realization of logic functions using these devices.

3.2.2 Synaptic Transmission

Signals are transmitted across the synapse by chemical transmitters contained in vesicles in the presynaptic knot, some of which,

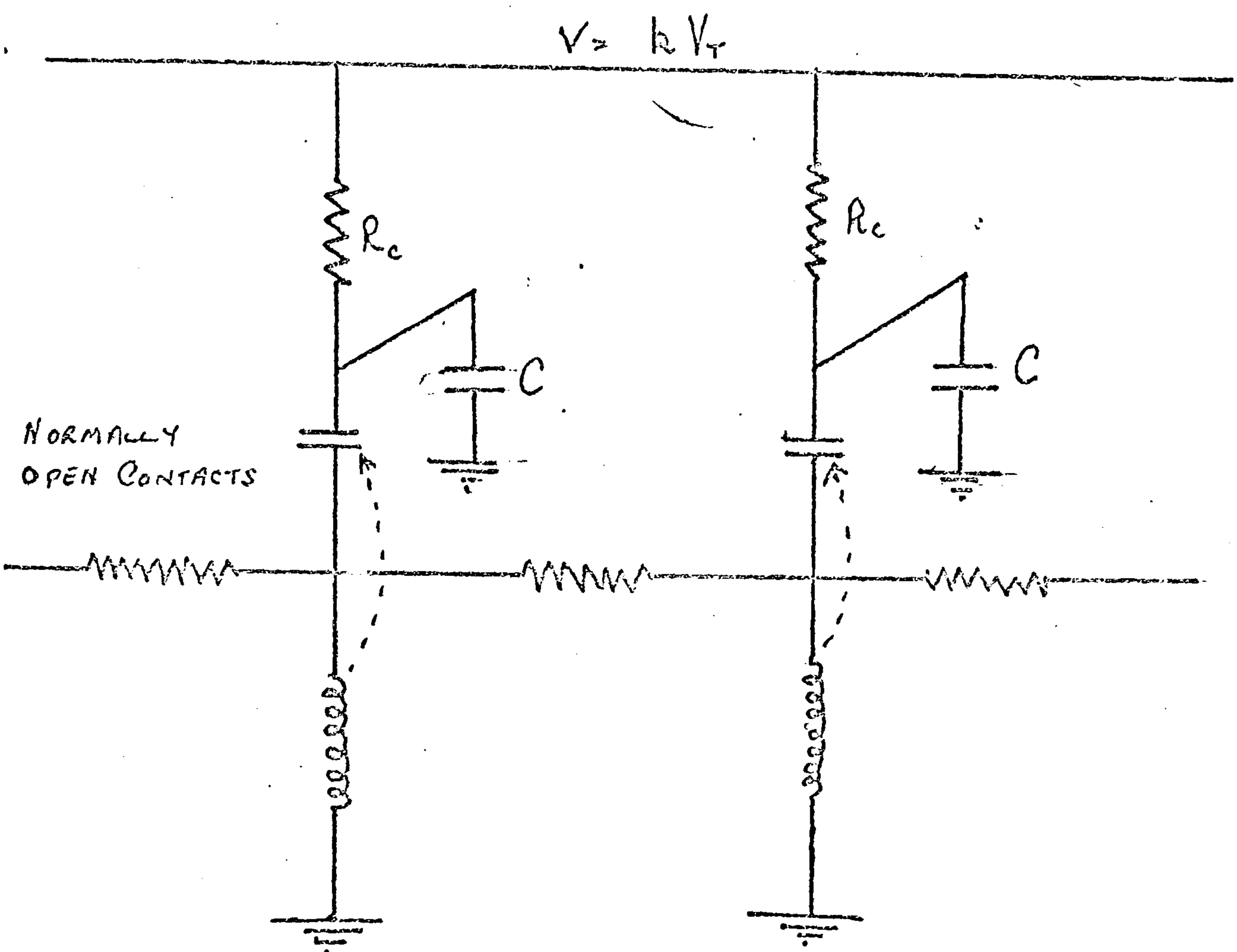

Fig. 3.1. Discrete-element Relay Neuristor Line

(After CRANE, 1962)

on the arrival of the action potential at that axonal ending, are discharged into the synaptic cleft. The implication of this is that an integral number of vesicles are discharged each time and thus the normal excitatory postsynaptic potentials (EPSP) are built up by an integral number of contributions or quanta.

Thus if all that quanta are of the same amplitude and the magnitude of the EPSP is proportional to the number of quanta from which it arises, a theory regarding the variation in the amplitude of the EPSP can be discussed. As the consequence of an arrival of the action potential there is a certain probability, p say, that a given vesicle is discharged into the cleft. Let p be the same for all vesicles and let the probabilities be independent of each other. If there are n vesicles then the probability that exactly x are discharged (and that, therefore, exactly (n-x) are not discharged) is given by:

$$P_x = \frac{n!}{x!\,(n-x)!}\, p^x q^{n-x}$$

where $q = 1 - p$. With these assumptions the EPSP varies in size on different occasions according to the binominal distribution.

The mean of the binominal distribution is $m = np$ and standard deviation is

$$\sigma = \sqrt{npq} = \sqrt{mq}\,.$$

In some experimental situations, it turns out that n is very large, while p is small in such a way that $m = np$ has a moderate value. Then the binominal distribution approximates to the Poisson distribution

$$P_x = \frac{m^x}{x!}\, e^{-m}$$

which has mean m, standard deviation $\sqrt{m}$. (See Griffiths, 1971).

3.3 Uttley's Conditional Probability Machines

Uttley (1956) suggested that as animals responded to a variety of configurations in the external world in the same way, these configurations, for the animal, must have resembled each other in some way. Similarly, there could have been a variety of responses to situations that appeared similar to the observer. Uttley suggested that "resemblance" was based on two known mathematical relations, the first being the INCLUSIVE relation of Set Theory; the second relation being that of CONDITIONAL PROBABILITY. From these two relationships it was possible to deduce the principles of design of a machine whose reactions to stimuli were similar in a number of ways to those of an animal.

The machine, like an animal, could assess resemblances between sets of input data, not between phenomena from which the data was derived, i.e. it assessed resemblances from an internal representation of the phenomena and not between the external configurations.

To make this problem amenable to analysis it was found necessary to idealize the form of input, abstracting some important factors. The input quantities to a nervous system contained a measure of intensity but Set Theory was concerned with properties which were either possessed or not possessed. Also, the input signals were not independent - in Set Theory no relation is considered between elements of a set other than that of inclusion in it.

He considered the simpler situation where each input quantity had only binary measure, i.e. it had one of two possible values, which were called "active" and "inactive". If input j was active the representation was said to possess property j. There was independence between all pairs of inputs, i.e. in a large ensemble of representations the fraction possessing property j was the same whether the ensemble possessed property k or not. It was considered, also, that there was no variation in the duration of the active state of an input, all inputs in a representation were active simultaneously, and that the intervals between representations were unimportant. The idea of neighbourhood between input channels was also abstracted — the transformation formed by the connections from the receptors to the input points of the machine need not then be topological.

Uttley defined two types of classification machine, one he called unitary and the other binary. The unitary machine simply connected an input corresponding to a particular quantity to units in which that property was represented. Thus if the machine had a number of inputs, j, l, k .... , etc., the j input would be linked with the units representing j, j and k, j and l, j and k and l, and so on. Thus if both j and k inputs were activated, this event would be recorded in the j, the k and the j and k units. This meant that the machine had to have 2^n classes if n is the number of inputs. The binary machine took both the input signal and its negation so that classes such as j and k but not l could be identified. This led to 4^n classes but as some of them were null classes (classes that have both the property and its negation of any of the inputs) only 3^n were of interest. The binary machine could, therefore, be constructed using 3^n units if care were taken in the wiring up of the machine. Although the connections, even in a unitary machine, became very complex if there were more than a small number of inputs, Uttley showed that the requisite connections could be made by connecting units to the input in a random manner without significantly degrading the representation of any particular unit in the machine. Uttley pointed out that there are parts of the nervous systems of animals that were apparently connected in a random manner whose function could be the classification of inputs. Any set of properties defined a class of representations — such a set of properties was called a pattern. If there were a total of n properties, there were ${}_nC_r$ ways of forming a pattern of r properties. The total number of patterns was $\sum_{0}^{n} {}_nC_r$ which is 2^n. Inputs must be combined in all possible ways; each combination of inputs must be connected to a unit; connections are either made or not made. A unit must operate if all the inputs connected to it are active – all units were of the same design.

For a machine described above with n inputs, there was one unit connected to input j which referred to a one-property pattern; there were n-1 units connected to input j which referred to two-property patterns, and there were ${}_{n-1}C_{r-1}$ units connected to input j which referred to r-property patterns. The total number of units connected to input j was $\sum_{0}^{n} {}_{n-1}C_{r-1}$ which was 2^{n-1} – this was half the total number of units. The probability of a connection from any particular unit to any particular input was, therefore, $\frac{1}{2}$; this suggested to Uttley that a statistical law might lead to a correct system of connections.

If the connections from the units to the inputs were made entirely random, but in such a way that P, the probability of connection from any unit to any input was $\frac{1}{2}$, then the probability of not being connected was also $\frac{1}{2}$; the probability of a unit being connected to a particular set of r inputs, and not being connected to the remaining n-r inputs, was $(\frac{1}{2})^r(\frac{1}{2})^{n-r}$, which is independent of r, It follows, for a machine of n inputs randomly connected to 2^nK units where K is a large number, that for each particular combination of connections there will be $K \pm \sqrt{K}$ units so connected. The apparently complicated connective system could be achieved in this simple manner, and all the different units would have approximately equal representation in the total population of randomly connected units. In parts of the nervous system of many animals there are systems of connections which appear to be random, and

Uttley suggested that their function may be that of classification of inputs.

The simple law, $P = \frac{1}{2}$, contained no reference to the distance between unit and input — from this law it was not possible to determine how different units were arranged spatially, so it was necessary to describe the random, root like connections from the unit in the following way.

For a unit at a given position relative to the input point, there was a probability of connection, P, which was a function of that position - this function was said to define a probability field. Such a function has been discovered by Sholl (1956) for the stellate and pyramidal cells of the visual area of the cat - it took the form

$$P = a \exp (-{}^{r}/r_0)$$

at any point, if P was the probability field for a single input, ρ was the total density of units and ρc was the density of units connected to the input, then $\rho c = \rho P$. If the special distributions of a set of inputs was known, then it was possible to calculate the density of distribution of the units connected to this set.

From the concept of conditional probability Uttley developed the conditional probability machine. The classification machine was incapable of learning and could mis-classify an object with an obscured characteristic. To surmount this obstacle Uttley suggested that instead of a unit having two states, i.e. one state if the event occurred and another if it did not, represented by, say, 1 and 0, the unit should be in a state represented by 1 when a set of properties occurs, and a state which can be represented by any value between 0 and 1, the unconditional probability as determined by past experience, if that set of properties did not occur. Given the unconditional probability the conditional probability can be calculated from the following. If P_{AB} is the probability of the simultaneous occurrence of A and B, and P_A denotes the probability of A and $P_{A/B}$ denote the conditional probability of A, given the evidence that the event B has occurred, then

$$P_{AB} = P_B \, P_{A/B}$$

$$\text{i.e.} \qquad P_{A/B} = \frac{P_{AB}}{P_B} \,.$$

Now, as the probability of an event, by definition, had a value lying between 0 and 1, and as it is easier to subtract than multiply using an analogue computer, a quantity R_A was introduced where,

$$R_A = -\operatorname{Log} P_A$$

$$\text{i.e.} \quad -\log \frac{P_{AB}}{P_B} = R_{AB} - R_A \,.$$

The quantity R_A can be identified as the rarity of the occurrence of an event, i.e. $R_A = 0$ when $P_A = 1$. Thus, to convert a classification machine into a conditional probability machine all that was required was that each unit incorporated a storage mechanism which grew in a logarithmic manner when the event does not occur, but decreased by a certain discrete amount when it did.

Suppose that, in a past ensemble of representations, the input quantities j and k had been as follows:

j	1111110000
k	1111110000

where 1 and 0 indicate the active and inactive states, respectively.

From this it appeared that j and k were related. The mathematical description of this situation is $P(^j/_k)$, the conditional probability of j given k, is unity. Thus if k occurred without j the machine would have had some reason for believing j did in fact occur, but was undetected. Partial positive dependence is shown in the following series:

j 0001111000

k 1111110000

in this case, unconditionally, $P(j) = 0.4$, and $P(k) = 0.6$; but conditionally, $P(^j/k) = 0.5$ and $P(^k/_j) = 0.75$. The occurrence of either property raises the probability of the other. Partial negative dependence is shown in the following series:

j 0000011110

k 1111110000

where the occurrence of either property lowers the probability of the other.

The relation of conditional probability was formed between properties, and sets of properties (patterns), on the basis of their joint occurrence in the same total representation, regardless of whether they possessed a common part; it depended on their relative frequency of joint occurrence, so it was not formed instantaneously - it depended entirely on the nature of past experience, so it could be acquired or lost.

A machine can be designed which embodies this principle of relationship. In a pure classification machine each unit had two possible states 0 or 1 depending on the presence or absence of that input. This could be extended so that the number of states of a unit becomes infinite, representing the probability of a pattern under all circumstances. Three different circumstances can be distinguished (i) if the set J occurred, the unit must contain a quantity representing unit probability - this condition was met in the pure classification machine; (ii) if no representations occurred at all, the unit was to contain, not zero as in the classification machine, but the unconditional probability of J as determined by past representations; (iii) if the set of properties k occurred, the unit was to contain $P(^J/K)$ the conditional probability of J, given that K occurs. Such a machine was called a conditional probability machine.

Consider a hypothetical experiment in conditioning. Suppose that the unconditional and conditional stimuli activated a set of inputs J and K respectively, and that the representation was as below:

Unconditioned stimulus J	1010	0011	1010	1010	1010
Conditioned stimulus K	0011	0011	0011	0011	0011
P(J/K)	1/2	3/4	4/6	5/8	6/10

In the first sequence of four representations there was independence, since $P(J) = \frac{1}{2}$ and $P(J/K) = \frac{1}{2}$. In the second sequence there was complete positive dependence, after it $P(J) = \frac{1}{2}$ as before, but P(J/K) had risen to $\frac{3}{4}$. In the next three sequences there was independence at first - the conditional probability falls, but more slowly than it rose. If, then on, there was always independence, P(J/K) tends to, but never reaches the limiting value of $\frac{1}{2}$.

If, however, there was complete negative dependence as in the following four sequences:

Unconditioned stimulus J	0101	0011	0101	1100	0101
Conditioned stimulus K	0011	0011	0011	0011	0011
P(J/K)	1/2	3/4	4/6	4/8	5/10

then the conditional probability falls rapidly to $\frac{1}{2}$; the effect of the negative dependent sequence was to cancel the effect of the positive dependent sequence.

The conditional probability P(J/K) is the unconditional probability P (J∪K) divided by the unconditional probability P(K). To make these quantities easy to work with, the unconditional probabilities were computed on a logarithmic scale, and since the probabilities lie between 0 and 1, the positive quantity $-\log P(J)$ was computed. This function arose so frequently in the treatment that it was given the name of the RARITY of J, and was written as R(J).

If the total number of past representations was m and the number possessing the pattern J was u, then

$$R(J) = \log m - \log u$$

$$\text{so} \qquad \delta R(J) = \frac{\delta m}{m} - \frac{\delta u}{u} .$$

Because of the first term on the right hand side, the quantity stored in the J unit had to grow logarithmically with the number of past representations - this was true for all units. Because of the second term, if the pattern J occurred (i.e. $\delta u = 1$), then the quantity stored in the J unit had to decrease by an amount $\frac{1}{u}$; this decrease in the stored quantity was the act of counting. Because when J occurs R(J) had to equal zero, the unit had to contain a gate, so that the desired output from the unit was obtained and not the stored value.

So far, the representations have been treated as timeless ensembles. As a first step in removing this abstraction, Uttley considered that the representations occurred uniformly in time at intervals T, then n, the total number of representations since the time t = o, was $^t/T$. The probability, P, of a pattern then became uT/t, which is the probability that the pattern would occur in time T.

The design of the unit now became simpler:

$$R = \log {}^t/T - \log u$$

$$\frac{\delta R}{\delta t} = \frac{1}{t} - \frac{1}{u}\frac{du}{dt} .$$

It was a property of such a unit that all events were weighted equally, regardless of when they occurred, or of the interval between them.

If a weighting function was introduced, so that the effect of a past event was less than that of a present one, there were significant changes in the nature and properties of such a unit. The quantity $\frac{\delta R}{\delta t}$ needed no longer to be a function of t, u and $\frac{du}{dt}$, but only of the present quantities R and $\frac{du}{dt}$.

The changed properties were as follows:

a) there was no particular time defined by t = o

b) there was no particular state defined by u = o, so the indeterminate quantity did not arise.

c) the extent to which R could be altered by an event was independent of time and depended only on R.

Any quantity which grew in the absence of events, and decayed during events, would provide some measure of the mean frequency of occurrence; the scale need not be logarithmic and the weighting function could take any form. An ionic concentration within a neurone might possess such properties, and so provide a measure of the mean frequency.

The principles of design that had so far been proposed were as follows:

a) the machine should consist of numbers of identical units connected in all possible ways to inputs

b) the J unit should count if the set of inputs J which were connected to it were all in the active state

c) the J unit should compute the weighted unconditional rarity R(J) of the set of properties J. In the absence of events, R(J) should grow; if J occurred R(J) should decrease by a certain amount.

d) if f(J) was the output of the unit, then

f(J) = R(J) if J did not occur

f(J) = 0 if J did occur.

A machine which embodies these principles was called an Unconditional Probability Machine.

The third requirement was that, when the set K occurred, the unit J had to contain R(J/K) instead of R(J). Since R(J/K) = R(JUK)-R(K), there had to be a comparison between the contents of the (JUK) and the K units; consequently a connection was required between them.

A J unit was called a super unit or a sub unit if $J \supset K$ or $J \subset K$, respectively. The computation of R(J/K) was considered for three possible relations between J and K.

J was a subset of K

J was a superset of K

J was neither a subset nor a superset of K.

If J was a subset of K, then if the set K occurs the set J occurs, so R(J) = 0; this was effected by the counting control, and has been discussed before.

If J was a superset of K, JUK = J, R(J/K) = R(J)-R(K), it followed that if K occurs the content of the K unit had to be subtracted from the content of the J unit.

The subtraction of the content of a unit, when its associated set of properties occurred, from the content of one of its superunits was called supercontrol. There was supercontrol by a unit of all its superunits.

If no other constraints had been laid down, there would have been two incorrect consequences. Firstly, if the set K occurred, then L, any proper subset of K occurred also. Consequently, if there were general control of supersets, R(L) would have been subtracted from the content of the J unit; this was in conflict with the requirement that R(K) be subtracted. But

$$L \not\supset K, \qquad P(L) \geqslant P(K) \quad \therefore \quad R(L) \leqslant R(K)$$

The conflict could be resolved correctly if it had been laid down that when there was multiple supercontrol of a unit, that which would cause the maximum decrease in rarity would be effective.

In the case of a set J which was not a superset of K, i.e. such that $J \cap K \not\supseteq K$ there would have been supercontrol of J from any set L for which $J \cap K \supseteq L$. As $R(J \cap K) \geqslant R(L)$ so, by the above rule regarding multiple supercontrol, effective supercontrol would have been from $(J \cap K)$, causing the content of the J unit to become $R(J) - R(J \cap K)$; but this is quite incorrect since $R(J/K) = R(J \cup K) - R(K)$. There is no general inequality relating $R(J) - R(J \cap K)$ to $R(J \cup K) - R(K)$, but this false supercontrol could be detected because it arose from a unit whose rarity had decreased by an amount $R(J \cap K)$ for which $R(J \cap K) \leqslant R(K)$.

To summarize, for a machine to have the function of effective supercontrol, the design rules were:

a) there had to be a counting control, which demanded zero rarity, and overruled supercontrol.

b) there had to be a connection from every unit to each of its superunits

c) if a set of properties occurred, the content of the unit associated with that set had to be subtracted from the content of each of its superunits.

d) if there is a multiple supercontrol at a unit, that which demanded the maximum decrease in rarity would be effective.

If J was not a superset of K, it would be necessary to consider the set $J \cup K$, which was a superset of K. If K occurred, supercontrol by the K unit of $J \cup K$ unit would cause its contents to become $R(J \cup K) - R(K)$; this quantity was $R(J/K)$. It was, therefore, necessary to transfer the content of the $(J \cup K)$ unit to the J unit, if K occurred. This was called subcontrol.

The following were the necessary design rules for a machine to possess the function of correct subcontrol:

a) counting control overode subcontrol

b) there were subcontrol connections from every unit to all its subunits

c) by subcontrol, the content of a unit was transferred to its subunit.

d) where there was multiple subcontrol, that which demanded the maximum decrease in rarity would be effective

e) subcontrol overode supercontrol if it was from a unit experiencing a greater decrease in rarity than does the unit demanding supercontrol - otherwise supercontrol overrode subcontrol.

The conditional probability machine had the following differences from a pure classification machine. The basic unit was no longer a two-state mechanism but one possessing a variable state. Also, there were interconnections, between units, which made possible the computations of the differences between the states of units. If these connections were always fully made, then all conditional probabilities would become unity, i.e. if one input became active it would have been as if all were active. However, as the units possessed variable states, the activity of one input, or set of inputs, only modified the probability of activity of all other inputs; some may have become more probable, others less; many would not be modified at all because, based on the past, they were statistically independent of the active set of inputs. For a conditional probability machine, the statement that two representations resemble one another could be replaced by the statement that the occurrence of one caused a high probability of the other. Such a machine has been built by Uttley (1956).

A conditional probability machine computed the probability of every set of properties under all circumstances. Such a machine could control effector mechanisms in many ways, but if it was to control them in an all-or-none manner when their probabilities exceed a threshold value, the machine could be of a simpler design.

For each set of properties J, it was necessary that the machine computed only a binary digit which was 0, say, if $R(J/K) < \varepsilon$, and is 1 if $R(J/K) \geqslant \varepsilon$. Such a machine was called a conditional certainty machine.

These two machines worked in a timeless world, it was assumed that all the inputs transmitted their signals at the same time. The conditional probability machine was no longer unable to classify events because properties were delayed in transmission, or were obscured so there was no internal representation of these properties at the input. The machine was now able to assign the event that it "sees" to the most likely class. There could even be a threshold mechanism which, if the probability of an event belonging to a certain class was exceeded, would assign that event to that class. Thus, if when properties A, B and C occurred, property D was usually present at a particular instance when A, B and C occurred, but no D was detected, the machine would "believe" that property D had occurred but it had failed to detect it. If the machine was working in a serial opposed to a parallel manner, e.g. using a scanning mechanism which sampled the input representing property A, then sampled the input representing property B and so on, then, after sampling inputs A, B and C it had calculated that there was a high probability of the input representing property D being active, it could be said to be predicting property D. This suggests that a machine, similar to the conditional probability machine, that is capable of prediction could be manufactured. The conditional probability machine does not strictly predict because the time vector is introduced by the machine itself. Events A, B, C and D all occur simultaneously, it is only the scanning process of the machine that introduces time, i.e. space has been transformed into time.

It is possible to design a machine which is similar in concept to a conditional probability machine which works in the time domain using the cross correlation coefficient, assigning a value between - 1 and + 1 to the occurrence of two events. If $x_1, \ldots\ldots, x_n$ are the numbers of one set and $y_1, \ldots\ldots, y_n$ are the numbers of another set, the coefficient of correlation between the two is:

$$\frac{\sum_1^n x_i y_i}{\sqrt{\sum_1^n x_j^2 \sum_1^n y_j^2}}$$

The numerator can be considered as the correlation for many purposes.

Now suppose x_1 was the value of the set at t_1, x_2 that at t_2, ... , x_n that at t_n, similarly for $y_1, y_2, \ldots\ldots, y_n$, it is now possible to calculate a coefficient of correlation between the two sets with a shift in time between them:

$$Q_{12} = \lim_{N \to \infty} \frac{1}{2N+1} \sum_{k=-N}^{N} x_{k+j} y_i^*$$

A set can even be compared with itself displaced in time:

$$Q_{11} = \lim_{N \to \infty} \frac{1}{2N+1} \sum_{k=-N}^{N} x_{k+j} x_k^*$$

If the data being analysed is continuous rather than discrete, i.e. the sequence can be represented by f(t), the above equations can be written:

$$Q_{12}(\tau) = \lim_{T \to \infty} \frac{1}{2T} \int_{-T}^{T} f(t+\tau) g^*(t)\, dt$$

and

$$Q_{11}(\tau) = \lim_{T \to \infty} \frac{1}{2T} \int_{-T}^{T} f(t+\tau) f^*(t)\, dt$$

where f*(t) is the complex conjugate of f(t) (WIENER, 1949).

3.4 GABOR'S NON-LINEAR FILTER, PREDICTOR AND SIMULATOR

The operation of an intelligent machine can be considered as a filter by which an input signal is transformed into an output. This can be in the form of the machine classifying objects, but, in order that it can be seen that it has, or has not, classified the object, the machine has to repond in some way, i.e. initiate some form of action, even if it is just a signal which can be considered as an output. Thus, a predictive filter attempts to change a given input signal into what the input signal will be at a given time in the future, or respond in a way that corresponds to the predicted input signal.

The mathematical difficulties involved in the design of an optimum non-linear filter led Gabor and others (GABOR, 1954; GABOR, WILBY & WOODCOCK 1960) to suggest that such a filter could be optimized through learning. He designed a filter which took the form of a flexible mathematical operator, capable of operating on the present and past values of any time series fed into it. The machine learnt by sampling the type of stochastic series which it was to filter or predict, together with the target function which it was expected to produce. The machine had a large number of adjustable parameters which were adjusted to minimize the error between its output and the target function. This error was judged by the criterion of least mean squares, as used by Kolmogoroff (1942) and Wiener (1949) in their linear filter theories.

i.e.

$$\overline{\left\{O(f(t)) - g(t)\right\}^2} = \text{minimum}$$

In the Wiener-Kolmogoroff theory of filtering most of the difficulty, and incidentally the elegance, was due to the fact that the authors consider signals in an unlimited frequency range.

However, in practice these signals would be transmitted through communication channels with a limited frequency range. It was shown in Gabor's paper (1954) that the most general functional of the past of a band-limited time function can be put in the form

$$O[f(t)] = \sum_{0}^{N} f_n r_n + \sum\sum f_{n1} f_{n2} r_{nm2} + \sum\sum\sum f_{n1} f_{n2} f_{n3} r_{n1n2n3} + \ldots$$

i.e. in the form of a polynominal of the samples, with certain coefficients. The first term represented a general linear filter — the r_n factors indicated the weight which a sample f_n, occurring n elementary intervals earlier, was given at the instant being considered. The second term contained the products of two samples, including their squares — their coefficients, r_{n1n2}, indicated the weight of a diad at n_1, n_2, at the given instant, and so on. Thus, the filter was a physical realization of the operator O. It had to carry out three types of operation:

a) delay the input by 1,2, ... N units, i.e. present the samples fn simultaneously with $f_0 = f(t)$ to the arithmetical unit

b) multiply these samples with each other

c) add them up, multiplied by adjustable coefficients.

To learn, the filter had to be capable of comparing this result with a target function using the criterion of least mean squares.

The assumptions involved in this filter were that the series was ergodic, i.e. it had the same statistical parameters in any long sample, and it was necessary that in the learning process the machine was able to abstract all relevant statistical parameters, and reproduce them.

3.4.1. LINEAR FILTER

Gabor (1954) showed that the optimum linear filter could be obtained, as nearly as was required, by a simple algebraic and numerical method which could be extended to non-linear filters.

The method was not mathematically rigorous but provided an approximate solution to a practical problem. The method used involved the deduction of the output of a filter, on the introduction of an input, from the response to a unit impulse.

For simplicity the operation was carried out in the rectangular finite waveband, as this enabled the use of the very simple expansion

$$\left[(f(t))\right] = \sum_{t_n = \infty}^{t} f(t_n) \; u\,(t - t_n). \quad (3.4.1.1.)$$

There was a small error committed by truncating the series at the instant t (the present), thus neglecting the effect of the u - pulses which belong to future instants t_n. If f(t) had been expanded into a physical response, which was exactly zero before the stimulus, this error could have been suppressed but at the cost of using a more complicated rule for the expansion coefficients. It was sufficient if the response decayed to an insignificant value in a time interval of less than $^1/2F$ before the stimulus, because times shorter than $^1/2F$ have no meaning in the waveband F (GABOR, 1954).

If the cardinal signal (3.4.1.1.) was put through a linear filter with the same bandwidth, which had an impulse response r(t), the output from the filter is

$$\begin{aligned}[f'(t)] &= \int_{-\infty}^{t} [f(t)]\, r\,(t-\tau)\,d\tau \\ &= \sum_{-\infty}^{t} f(t_n) \int_{-\infty}^{t} u(\tau - t_n)\, r\,(t-\tau)\,d\tau \\ &= \sum_{-\infty}^{t} f(t_n)\, r_u\,(t - t_n) \qquad (3.4.1.2)\end{aligned}$$

$r_u\,(t - t_n)$, was the response of the filter to a u - pulse or "sinc" signal centering on t_n ($U_n = \dfrac{\sin 2\pi F(t - \frac{1}{2}F)}{2\pi F(t - \frac{1}{2}F)}$):

As the signal, as well as the response of the filter to it, was completely described by their values at the sampling time t_n:

there was no need to consider other time instants. If $n = 2F(t - t_n)$, where n is a positive integer, the present corresponding to $n = 0$, $f_n = f(t_n)$ and $r_n = r_u(t - t_n)$, the signal behind the filter is

$$[f'(o)] = \sum_{n=0}^{N} f_n r_n$$

where N is a sufficiently large number.

From the criterion of least mean squares, we have:

$$\overline{([f^1(o)] - x(d))^2} = \min$$

where d is an integar, positive for delays, negative for predictions.

$$\begin{aligned}\overline{(f^1(o) - x(d))^2} &= \overline{\left[\sum_{0}^{N} (x_n+y_n)r_n - x(d)\right]^2} \\ &= \sum_{n=0}^{N}\sum_{m=0}^{N} (\overline{x_n x_m}+\overline{y_n y_m}+\overline{x_m y_n}+\overline{y_n y_m}) r_n r_m \\ &\quad - 2\sum_{n=0}^{N} \overline{x(d)(x_n+y_n)}r_n + \overline{(x(d))}^{2} \\ &= \sum_{n=0}^{N}\sum_{m=0}^{N} \phi_{ff}(n-m)r_n r_m - 2\sum_{n=0}^{N} \Psi_{xf}(n-d)r_n + \overline{(x(d))^2} = \min \qquad (3.4.1.3.)\end{aligned}$$

where ϕ_{ff} is the autocorrelation function of the raw signal and Ψ_{xf} its cross correlation function with the message x.

The result is a positive-definite quadratic form in the response samples r_n. Minimizing this expression leads to a system of N + 1 linear equations for the N + 1 values of r_n.

$$\sum_{m=0}^{N} \phi_{ff}(n-m) r_m = \Psi_{xf}(n-d)$$

The large number of linear equations can be solved by Southwell's relaxation method, because they have a symmetrical matrix, as they have been derived from minimum conditions.

3.4.2 NON-LINEAR FILTERS

The only information on the statistical structure of the message and of the noise which was made use of by a linear filter, was contained in the autocorrelation function ϕ_{ff} and in the cross correlation function Ψ_{xf}. This meant, in essence, that only the power spectrum and a cross-power spectrum were known. The information in ϕ_{ff} and in Ψ_{xf} contained just a rudiment of shape discrimination, just enough to recognize "simple echos". If there were recurrent symbols in the signal f, consisting of two peaks, the autocorrelation function would indicate them as one peak. Also the polarity of the peaks in relation to each other could be determined, but not their order. Similarly, $\Psi_{x\xi}$ would have a peak if the noise consisted of a simple echo.

One way of obtaining better discrimination is to introduce higher-order correlation functions. Correlation functions of the K - th order are sufficient for the specification of symbols containing K peaks.

The equation for the linear filter,

$$f'(0) = \sum_{0}^{N} f_n r_n$$

could be extended as follows

$$f'(0) = \sum_{0}^{N} f_n r_n + \sum_{n_1}^{N}\sum_{n_2}^{N} f_{n_1} f_{n_2} r_{n_1 n_2} + \sum_{n_1}^{N}\sum_{n_2}^{N}\sum_{n_3}^{N} f_{n_1} f_{n_2} f_{n_3} r_{n_1 n_2 n_3} + \dots$$

If the least mean square criterion is applied, we have equations of the type

$$\sum_{0}^{N} \phi_{ff}(n-m, n-n_1) r_n + \sum_{0}^{N}\sum_{0}^{N} \phi_{ff}(n-m, n-n_1, n-n_2) r_{n_1 n_2} = \Psi_{xf}(n-d, m-d)$$

which is the second order response.

The large number of linear equations involved in the solution of the above, means that even with the relaxation method a large amount of calculation is needed. Even with only 10 sampling points, there are 10 responses of the first order, 45 of the second order, 240 of the third order and so on, with an equal number of equations. Even worse is that, to establish these equations, data must be collected on the higher-order correlation functions of the order of the square of these numbers.

The filter was built (GABOR, WILBY, and WOODCOCK, 1960), the coefficients being represented by 96 potentiometers. The value of the non-linear transfer function was read off these potentiometers enabling the function to be represented by a 96 - term polynominal.

3.5. Homeostat

The homeostat was a machine built by Ross Ashby (1952) which demonstrated ultrastability, i.e. it was able to keep its own variables within limits that ensured the survival of the system. It consisted of four units each of which carried a pointer mounted on a pivoted magnet. The machine selected a state which kept the angular deviation of the four magnets at zero, or returned them to that position if they were disturbed. The pointer dipped into a trough of water, across which a potential gradient was generated by electrodes at each end, so that, if any one of the magnets were disturbed from its central position, there would be a d.c. output from the unit proportional to the excursion of the magnet from its central position. This signal was applied to the grid of a triode and hence controlled its anode current. If this current was more, or less than, the quiescent current, this would indicate the magnitude and also the direction of the disturbance. All four units were joined together so that the output on one unit became the input for all the other three units, and thereby each unit received an input from each of the other three units. These inputs acted on the unit's magnet through three coils, so that the torque on the magnet was approximately equal to the algebraic sum of the currents in the coils. There was also a coil in each unit which received a current proportional to the unit's output, so that feedback control was introduced into the system. Before each input current reached its coil, it passed through a commutator which determined the polarity of the current in that coil, and through a potentiometer which determined what fraction of the input reached the coil.

As soon as the system was switched on, the magnets were moved by the currents, which modified the movement of each other, and so on. If there was sufficient viscosity in the troughs, the four variable system of the magnet positions was approximately state determined. To this system the commutators and potentiometers acted as parameters.

When these parameters were given a definite set of values, the magnets showed some definite pattern of beahviour, for the parameters determined the field and thus the lines of behaviour. If the field was stable, the four magnets moved to the central position, where they actively resisted any attempt to displace them. If displaced, a co-ordinated activity brought them back to the centre position. Other parameter settings could have given rise to instability, in which case runaway would have occurred and the magnets would have diverged from the central position with increasing velocity - till the pointers hit the end of the troughs.

The inputs can, however, instead of being controlled by parameters set in by hand, be sent through similar components arranged on a uniselector by the use of a switch. In Ashby's homeostat the values of the components on this switch were deliberately randomized by taking actual numerical values from the Fisher and Yates' table of random numbers. Once built on to the uniselectors, the values of these parameters were determined, at any moment, by the position of the uniselectors. Twenty-five positions on each of the four uniselectors (one to each unit) provided 390,625 combinations of parameter values.

A further refinement was the use of a relay which represented the essential variable of the system. Its contacts closed when, and only when, the output current exceeded a certain value. When this happened the coils of the uniselectors were energized, causing the parameters to alter. The power to these coils was interrupted by a device that allowed the power to test the relay's contacts only at an interval of one to ten seconds (which could be adjusted). Thus if set at 3-second intervals, at every third second the uniselector would either move to new values (if the current in the relay coil exceeded the limits) or to stay where it was (if the relay coil current did not).

The uniqueness of the homeostat as a controller was that it did not matter how the connections were made from the homeostat to the system it was controlling because it would always alter its output to control the system within predetermined limits, if given enough time.

4.1. Introduction.

The concept of holography was introduced by Gabor in a paper in 1948, and further development by him in later papers (1949, 1951a; 1951b; 1952). He chose the name, 'holography,' from the Greek, as the new technique involved the recording of the whole of the message in a wave front. Thus, the total information in a wavefront, including both phase and amplitude information, could be recorded, as opposed to the normal photography in which only the amplitude information is recorded. The phase of a wavefront is a meaningless concept unless there is some standard against which to compare the phase of a given wavefront. In holography the reference was supplied from a homogeneous coherent background illumination, which was caused to interfere with the wavefront from the scene to be recorded. Gabor showed that this system was reversible in the sense that, if the interference pattern of the two wavefronts was recorded on a photographic plate, the wavefront of the original scene could be reconstructed by placing the photographic plate in the same homogeneous coherent background illumination.

Gabor was interested, principally, in using the full resolving power of an electron microscope which could not be realized, due to the inadequacies of the electron optical system. He reasoned that, if the hologram, constructed using the wave properties of electrons, could be enlarged by a photographic method, then illumination of a longer wavelength could be used to reconstruct the image. If light was used for reconstruction, then the image could be viewed through an optical system, with less faults. However, because of the lack of a coherent light source, and the use of an in line system (which meant that the virtual and real images were superimposed on each other), the full potentialities of the system were not immediately obvious.

The coherence of a source of light is universally proportional to the width of the spectral line of that source which is always finite. Even a high pressure mercury lamp is emmitting radiation of a number of frequencies, albeit very close to each other, and so the emitted wave is no longer a pure sine wave. Thus the wave envelope is no longer two parallel lines, but has undulations. The length of the wave that can be considered as having an envelope of constant amplitude is termed its "coherence length," which in the case of a high pressure mercury is about 0.1mm. It was not until the laser, with its powerful coherent beam, became available in 1962 that holograms were systematically investigated, high quality three-dimensional images were reconstructed from two beam holograms, a year later (LEITH and UPATNIEKS, 1963), as predicted by Gabor.

At the same time attempts were being made to unify communication theory and optics (ELIAS, 1953; LEITH and UPATNIEKS, 1962), using such notions as modulation, demodulation, filtering, and so on, to describe such phenomenon as holography in optics. The concept of Fourier transformations was also introduced into optics, thus allowing complicated spatial or temporal expressions to be expressed as simpler frequency components, which has been so fruitful in the analysis of electronic circuits.

The principle of the hologram dates back to the very beginning of the 19th century when Young, wishing to demonstrate the wave properties of light, passed a ray of sunlight through two pin holes, side by side in a dark room, and observed the resulting pattern on a screen. As the light arriving at the holes had started at a point source and had travelled equal distances, it was coherent; the two holes were acting as two in phase sources. As all the points on the screen, with the exception of the central one, were not equi-distant from the two sources so the light from these two points was no longer necessarily in phase at the screen—the two waves interfered with each other to produce a series of dark and light fringes. To produce a large number of such fringes requires an extremely coherent source – Young's experiment, for example, only produced a few fringes. In holography the interference is between a reference wave and a wave from the object under investigation, usually part of the reference wave that irradiates the object. The two incident waves thus produce interference fringes which can be then recorded on a photographic plate. This photographic plate can then be used to reconstruct the wave front emanating from the object, by simply shining a coherent beam along the same direction as the reference beam. As the only way of seeing an object is by way of this wavefront (the eye cannot distinguish between the wavefront created by the hologram and that from the real object), the reconstructed image is thus a true three-dimensional representation.

The reconstruction process can be considered from several standpoints, the simplest is to regard the photographic plate as a diffraction grating. Huygens pointed out that light from a point source can be regarded as radiating in a sphere, just as water waves radiate in circles when a stone is dropped into the centre of a still pond. Each point on the spherical wavefront is itself a point source, i.e. the centre of a spherical wavefront, except (as the wave cannot suddenly reverse and travel back towards the source) only the forward travelling hemisphere has any physical meaning. Thus, the wavefront is an expanding sphere as long as it does not meet any obstacle in its path. At a suitably large distance from the source, the radius of curvature of the spherical wavefront will be sufficiently large for it to be regarded as a plane wavefront, and the rays of the beam will travel in parallel lines. However, if such a wavefront encounters an obstacle, such as a screen with a hole (or a slit) in it of comparable size to the wavelength of light, the light emanating will no longer have a plane wavefront but a truncated parabolic one, so the light appears to diverge from (or bend round), the edges of the slit. If the apperture is not a singleton, but one of many, the whole of the wavefront from a point source, or for that matter any coherent beam, may be altered so as to appear to come from another source. The diffraction pattern on the holographically constructed photographic plate is such that when it is illuminated in the right direction by coherent light of the right wavelength, i.e. the reference beam, the emerging wavefront appears to come from point sources which correspond to points on the original object, so that a three dimensional image is formed of the original object. It is possible to correct the optical properties of the viewing system a posteriori. Thus, for instance, a three dimensional scene may be brought into sharp focus over an arbitrary depth. It is also possible to translate the observation point, to perform optical filtration of the spatial structure of the object and, in particular, to remove aberrations of the optical image-forming system . It is also possible to perform interference between two light beams which are not superimposed either in time or space.

With the coming of the laser, larger holograms were possible. This meant that holograms no longer consisted of just one interference fringe pattern, but a large number scattered over the whole plate. The image was thus strengthened enabling more resolution in the re-constructed image. The image could also be reconstructed even when the hologram was broken into small pieces, as long as the piece used for reconstruction contained the whole pattern. The diffusion of the pattern was obtained by using scattered light, which could be obtained either by using the object as a scatterer, or passing the laser beam through a diffusing medium before it reached the object. The scattering of laser light by apparently smooth surfaces can lead to laser speckle, a form of noise.

Further developments have led to the realization of deep or volume holograms (DENISYUK, 1962; VAN HEERDEN, 1963), which were three dimensional interferograms. The wave front interfered with the coherent background throughout the thickness of the emulsion, and so did not yield a superposition of the real and imaginary images. The information that can be introduced into this type of hologram turns out to be much richer than that contained in the conventional hologram.

Gabor(1966) investigated a scheme of holographic recording in a three-dimensional medium, which consisted of the registering of a set of standing waves created by the object and reference beams. This hologram acted as a volume diffraction grating during the reconstruction, i.e. a resonant structure which yielded a diffraction picture for certain wavelengths and angles of incidence. This reconstruction occurred only when the reconstructing beam was analogous to the recording beam in angle and wavelength. The recording of each object point in this system turned out to be uniformly distributed throughout the recording volume, therefore, even significant damage of the holograms was not important, leading simply to degradation of the signal-to-noise ratio. Also, each point of the hologram contributed to the reconstructed image, thus the memory possessed associative properties, i.e. the selection of the necessary information was made, using a certain sign rather than the address of the cell in which it was stored. This type of hologram is analogous to the use of a crystal as a three-dimensional diffraction grating for x-ray radiation, as opposed to a normal two-dimensional diffraction grating.

Holograms are also capable of pattern recognition. This is based on the ability of the hologram to pick out from a group of objects only those whose "images" are recorded in it. Suppose A and B are two coherently radiating objects, in particular they may be any objects illuminated by a sufficiently coherent laser. If the radiation is capable of creating in a certain plane an interference picture - a system of standing waves - then a photographic plate may be placed there and a hologram obtained. By illuminating the hologram A + B with an ideal copy of the initial wave front of one object, a reconstructed wave front capable of faithfully imaging the other object will be obtained. The hologram will transmit only that part of the spatial spectrum which is close to the spectrum recorded on it. Thus, it will respond only to the image of one of "its own" objects, with the condition that the object be placed in the appropriate position. (Normally, one of the objects will be a point source emitting a spherical wave front, or plane wave front if the source is at infinity - the rays delimiting this wave front constitute a beam, known as the reference beam.) If, for instance, the object B is a combination of point sources comprising the code of the letter, then the hologram A + B illuminated by the letter A permits the reconstruction (i.e. the extraction from the hologram) of the code B. Using recordings with various angles on the same hologram, it is possible to record a large number of letters, thus providing a new channel of communications between man and computer which could liberate the operator from the manual introduction of data. Moreover, it might be possible, using this method, to enable a computer to recognize multidimensional images.

There are a number of beams which correlate sharply with themselves, i.e. those which issue from a fingerprint, or those from a Chinese idiogram, and in an extreme case also those from a piece of frosted glass. They correlate sharply with themselves in the sense that the number of invariants in the beam greatly outnumbers possible variants, i.e. a fingerprint may be presented in a limited number of ways, its size and orientation may be changed, but there are a large number of properties of the beam that are not changed when it is transformed in size and orientation. This means that there is a large amount of redundancy. Thus, if the beam is considered as being made up of beams, A, B, C...... and so on, each beam A, B, C...... is capable of uniquely defining the total beam. Then, whenever the total beam is present, there will always be a sub beam untransformed. So, if a hologram is constructed of A + B + C + code, the code will be produced no matter how the total beam is transformed. Hence, it is quite possible, for instance, by means of a hologram to translate a Chinese idiogram into its corresponding English sentence, and vice versa, and even translate a sign which humans can read into a form that a machine can read. In other words, a hologram can be used as a universal translator.

Coherent light generally is needed to construct a hologram. However, methods using monochromatic, spatially incoherent light have been described (METZ et al, 1961; COCHRAN, 1965; LOHMANN, 1965). Recent incoherent light schemes are based on the idea of forming two images and producing interference between them. In one such system (STROKE and RESTRICK, 1965) the light from the object passed through a beam splitter and was divided into two portions, each passing through a lens to a mirror and back again through the lens.

Each formed an image, but in a different place. Although within each image all the image points were incoherent with each other, each point was coherent with the corresponding point of the other image. At a specific plane each such coherent pair of points produced an interference pattern, and the summation of all patterns constituted a hologram, from which an image could be regenerated.

The scheme works well for a simple object of only a few points, but breaks down as the object becomes more complex. This is because the light intensity from each coherent point pair is of the form:

$$a_0 + a_1 \cos \phi(x,y)$$

where ϕ is a function determined by the path difference between the interfering points. The second term represents the fringe pattern and carries all the information. The hologram of a complex object is formed by the summation of many such expressions, one for each point pair. The a_0 terms add directly but the a_1 terms add randomly, since ϕ is different for each pair. As the number of image points increases, the constant a_0 or bias term grows more rapidly, and the fringe constrast decreases. Eventually, the fringes are lost in the system noise.

A method has been described for removing the a_0 terms before making the hologram (KOZMA and MASSEY, 1966). Vibrating one of the two interferometer mirrors, so that it underwent a periodic displacement $d = d_0 \cos pt$, produced a similar time modulation of the fringe components, but not of the bias. An array of photo detectors, one for each resolution element, was substituted for the hologram. Connected to each detector was a band pass filter that passed the time varying component, but rejected the bias component. The signal was then converted back to light on a point by point basis, and recorded as a hologram. With the bias term eliminated, the obstacle to incoherent light holography had been overcome. This system may seem enormously complex, but in practice the large number of photodetectors and filters could be replaced by, say, an image orthicon and associated electronics.

Considerations like those discussed above have led some writers (e.g. PRIBRAM, 1971) to consider the hologram as an analogue to animal memory, and even the basis of intelligent animal behaviour. The points of similarity are :-

1) the immunity of the memory to even quite extensive damage;

2) the large storage capacity;

3) the associative nature of the memory.

The brain, if this theory is tenable, would have to be conceived of as a volume hologram, standing waves being produced in the synaptic junctions in the form of Pribram's micro potentials (PRIBRAM, 1971). A further refinement is also conceivable in the form of cyclic accessed memory. As it will be shown, volume holograms are very sensitive to the orientation of the reconstructing beam. Thus if the beam is rotated, it is possible, if several holograms have been recorded with reference beams from varying directions, to generate a whole series of images. Thus, it is possible to imagine a memory where it is not necessary to know the location of a particular piece of information in order to recall it. If it is needed to recall the name of a school friend, for example, the system would go through the whole of the memory, or subset of the memory, until it came up with a memory that linked the idea of school to a picture of the members of a particular class. It would then continue to cycle the memory store until it came up with a memory that linked the idea of the friend to a particular face in the class. Finally, it would continue to cycle until it found a memory that linked the face to a particular name. If the name and face link had been laid down in the memory first, followed by class and face link, and then the school class link, the process would take the time required for three scans of the memory. If they were laid down in the reverse order, the time taken for the search would be that required for one scan. This type of memory would have several advantages over one with information assigned to a particular location. The laying down of the memory would be essentially random, i.e the memory would be laid down when the system experienced it, no attempt would be made to order the memory according to a priori criteria. The first cycle through the memory, thus, probably will be unsuccessful, but it will enable the few characteristics about the school friend that are known at the start (there must be some awareness that there was a school friend to initiate the search) to be magnified, therefore making the success of the second cycle more probable. The beam that is being rotated would consist of all the characteristics known about the friend at that point of time, and it would continue to grow until it contained the characteristics that will generate the image of the name.

If the system was dealing with a problem, there could be sufficient variation in the memory for a solution to be generated, in the manner of Ashby's intelligence amplifier (ASHBY, 1956). A further randomizing element will be introduced because of the limit of resolution of a hologram. Thus, there might be a link generated which is not strictly relevant or which might lead to a solution, i.e. the name of another friend with a similar name. This will enable a certain amount of random generation of solutions, preventing stagnation of the system, but these solutions will tend to be close to those required, because if the input from the problem is sufficiently close to the reconstructing beam for a particular hologram for it to generate an output, the chances are that the output is a close approximation to the solution required. For a practical system the memory might have to be subdivided into sub memories with some form of cross-referencing, due to the time needed for the scan.

In the practical application of this system difficulties would be involved because of the lack of coherence, especially in the visual world, in the environment. A possible solution is one involving the use of a method enabling the construction of holograms in incoherent light.

Over the past few years there has been an amalgamation of optics with electronics, as exemplified by television.

There are two types of television cameras. One, the iconoscope, consists of a photosensitive surface from which electrons are liberated, and collected by a positively charged anode nearby. If this electron current is passed through a resistor, a voltage proportional to the brightness of the object is obtained. Unfortunately, however, this voltage is merely a measure of the total number of photo-electrons emitted, i.e. the total number of photons hitting the cathode from the whole object at once. In order to measure the intensity for each picture dot individually, each dot must be insulated from its neighbours, which can be realized by forming droplets of photosensitive silver-caesium on a flat plate of non-conducting mica.

If a thin metal coating is placed on the other side of the mica, a matrix of capacitors will be formed. The total charge on this coating will then be the sum of all the individually induced charges. This charge remains constant for the short time needed for one complete scanning of the picture, and an electron beam discharges each droplet in turn, causing the charge on the coating to drop by the amount of charge induced by that particular droplet. Immediately the beam passes on to the next droplet, the light from the televised scene will cause the droplet to be ionized again and the charge on the coating is now the total charge minus the charge that was on the next droplet. If the action of the electron beam is synchronized to the beam in a viewing tube, the charge distribution in the droplet matrix can be coded and transmitted to a television set.

The above type of camera suffers from two main disadvantages, a) the electronic beam causes a scattering of surplus electrons, which in turn cause ionization of the other droplets and b) the camera has low sensitivity to light. The other type of camera tube, the image orthicon, overcomes both of these shortcomings.

In the image orthicon the caesium-silver is sprayed on the inside of a glass plate so that the electrons are ejected away from the source of the light, and into the camera. Free electrons tend to emerge from a metal at right angles to its surface, so that the pattern of the image is preserved as the electrons travel through space. The electrons then, having been accelerated by an electrical potential, encounter a thin glass plate target (one ten thousandth of an inch thick) where they each knock out several secondary electrons. The secondary electrons are then swept out of the way by a grid of fine mesh with a small positive charge relative to the glass.

An ionic image is now left etched on the glass. Since this glass is very thin, this charge image passes through the glass by electric conduction and it is, therefore, available on the back of the target. This image is preserved by virtue of the fact that glass is a good insulator across its surface. The charge image is now scanned by an electron beam from a gun situated on the far side of the target, at the back of the camera tube. The electron beam is slowed down by an electrostatic field as it approaches the glass so that, when no picture is being televised, it just fails to reach it. Then it is accelerated by the same field back towards the gun, but is intercepted and collected by an anode. When a picture is being televised, however, those points on the glass target which have been left with a positive charge will snatch electrons from the scanning beam as it passes over them. The "dark" parts of the image, with no positive charge, will not. The intensity of the gun beam returning to the anode will therefore be continuously altered, or modulated, by the ionic image on the target, and thus provide a picture signal (FINK and LUTYENS, 1961).

If there is such a mechanism in the animal eye, e.g. the micro potentials in the synaptic junction forming an ionic image in the layers of the retina which are capable of being scanned and modulating an input signal, it may be that two images are formed and then allowed to interfere (see ENOCH, 1967).

Finally, it now appears possible to actually generate a three-dimensional image from a set of computed image co-ordinates, by generating the hologram, capable of displaying the desired image, from the set of computed image co-ordinates. This could be analogous to the generation of abstract hypotheses, i.e. the introduction of links never actually experienced, into the memory store.

The advantages of holographic methods of information processing lie in the fact that in holography the initial information is processed in its entirity and almost simultaneously through the entire field. Such operations as scanning or spreading the image into lines, which are necessary in electronic systems, or the separation of the real and imaginary part of the complex function into different channels, are completely eliminated in the coherent optical system.

4.2. Interference Memories (Volume Holograms)

Suppose that two point sources, i.e. one providing a reference beam and the other constituting a point of the object, are placed near to each other, then the two waves from the two sources will interfere with each other. If the contours of constant phase difference were to be drawn, they would be closest at the centre of a line joining the sources and would become wider as the distance from this line increased. Again, near to this line the contours would be parallel to it, but they would tend to become perpendicular as the distance increased.

If a recording medium, say an Eastman Kodak spectroscopic plate which has an emulsion thickness of 15 microns (the normal photographic plate on which holograms are constructed), is placed in the far field- still between the parallel lines passing through the two point sources, perpendicular to the line joining the two sources, but at some distance from that line - the contours or fringes will be widely spaced, more widely spread than the emulsion thickness of the holographic plate. The hologram that will be recorded will be of the early Gabor type, and the emulsion thickness can be neglected.

Suppose the photographic plate is moved nearer to the datum line joining the two sources, still between the two lines perpendicular to the datum line and passing through the two point sources, the fringes will be closer together and the spacing will be comparable to the thickness of the emulsion. A hologram recorded in this position exhibits great orientation sensitivity, i.e. in the reconstructional process the orientation of the hologram in the illuminating beam is crucial. If, for instance, the hologram is rotated slightly from the optimum reconstruction position, approximately 5° for the Kodak plate, the image disappears. This is because the fringe patterns are acting as diffraction gratings with a finite width, so that only light of a limited orientation will be diffracted at the entrance of the slit, (which is now a tunnel at an angle to

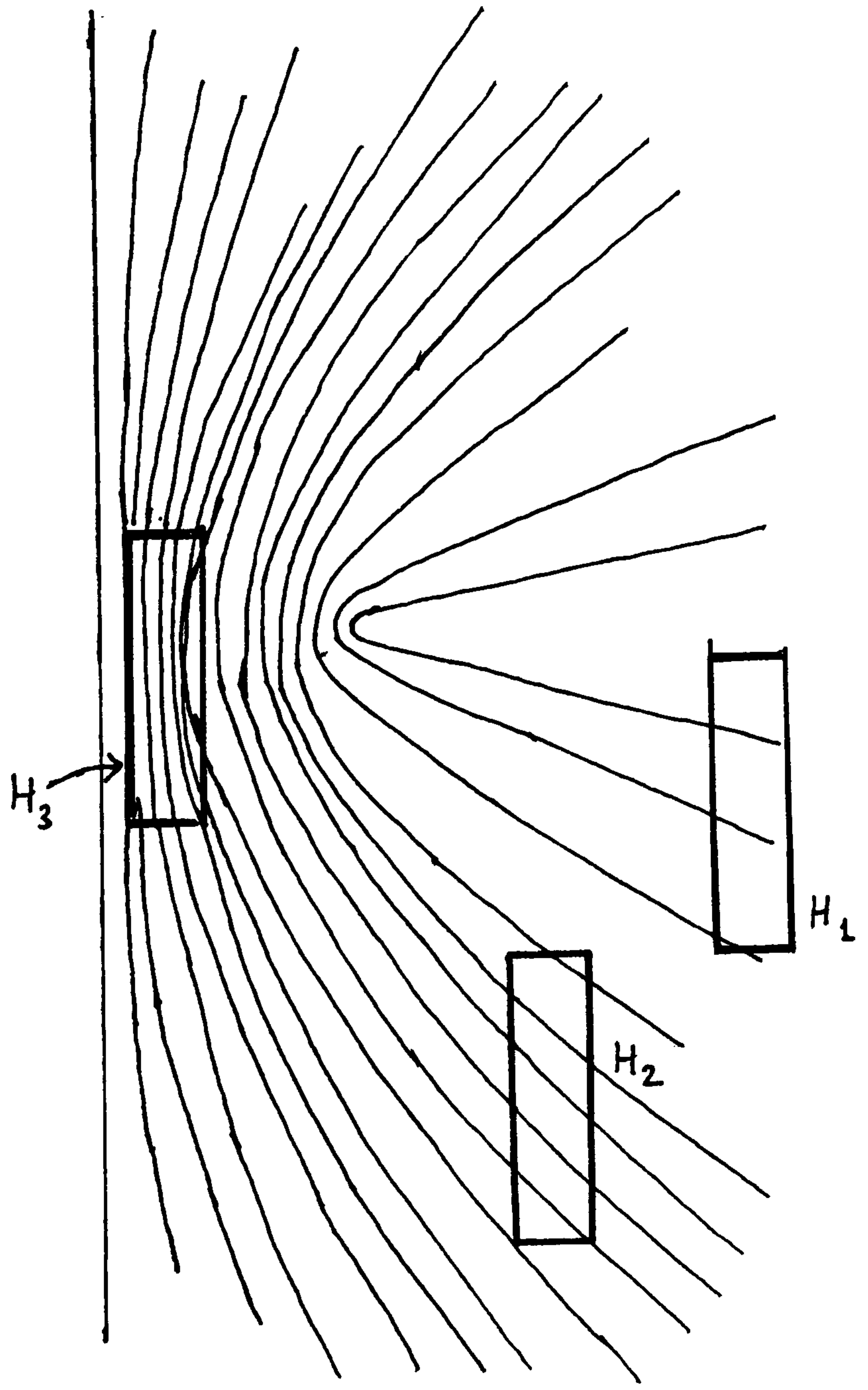

Fig. 4.1.

Behaviour of holograms recorded on thick emulsions dependent on where the hologram is placed between two point sources. H_1, H_2 and H_3 represent three possible positions of holograms in the fringe pattern representing contours of constant phase difference between the two sources.

(After LEITH, 1966)

the surface of the photographic plate) to emerge at the exit. As the sides of this type of grating will act as mirrors, a further restriction is placed on the direction of the illuminating beam. Thus the reflection from the sides of the grating must reflect the beam into the first diffracted order while the grating formula conditions are satisfied—if these conditions are not simultaneously satisfied, no diffraction will occur.

Using this rotation technique, an experiment described by Van Heerden (1963) was performed at the University of Michigan. Five holographic images were stored in successive exposures, with the plate rotated slightly between exposures. When the plate was rotated in the readout beam, the images were produced in succession, resulting in a short holographic "movie". This experiment reproduced only five to seven pictures, but thicker emulsions could conceivably reproduce several hundred.

If the photographic plate is moved to a position near the centre of the line joining the two point sources, then the reference beam and the object beam are introduced from opposite sides of the plate. The recorded fringe patterns, in addition to being closely packed, lie roughly parallel to the emulsion surface. The introduction of the reference beam from the back surface was first described by Denisyuk (1962; 1963), who also recognized the similarities with a process for colour photography described by Lippmann (1894). It also has some very interesting properties.

In the Lippmann process, colour images were produced on black and white film by recording standing wave patterns in the emulsion. It was developed about 1881 but has never been applied commercially. A wave from an object entered a photographic plate from the non-emulsion side and passed through the emulsion. On the other side of the emulsion the wave encountered a mirror (bath of mercury in the original scheme) so that it was reflected back into the emulsion. The two waves reacted with each other to form a standing wave (like vibration of a violin string), with the maxima half a wavelength apart with a minima in between. Thus, when the plate was developed, the silver particles formed surfaces within the emulsion.

When this developed plate was viewed in white light, each surface reflected a small fraction of the incident light. Light from the surfaces combined, and reinforcement occurred for the wavelength that produced the surfaces, but not for other wavelengths. Each part of the recorded image reflected the colour of the original image, and the observer saw in the light reflected from the plate the image in its natural colour. Denisyuk noted the similarity of the Lippmann process to holography. In the Denisyuk system a beam of coherent light passed through the plate, was reflected by an object lying on the other side of the plate, and the interference between the direct and reflected beams produced a recording within the plate. Because of the selectivity of the wavelength and beam orientation colour holograms could be made by the use of laser beams with wavelengths equivalent to the three primary colours (LIN et al, 1966; LEITH et al, 1966; HOFFMAN et al, 1965). Pennington and Lin (1965) used laser light for the image reconstruction, but it has been shown that volume holograms are capable of reconstructing colour images with white light (STROKE and LABEYRIE, 1966).

Other recording media have been used for volume holograms apart from photographic emulsion, e.g. KBr crystals. The crystal was heated up to $80^{o}C$ and when irradiated by laser the colour centres whitened, so that an interference pattern could be recorded. On cooling the crystal the hologram was "developed" enabling an image to be reconstructed. In an experiment, thirty different images of dimension $2.5 \times 2.5 \times 0.2\ cm^3$ were recorded, the theoretical limit is 500,000. The amount of information that could be stored in a volume hologram is about 10^{12} bits/cm^3 (STROKE, 1969). The practical difficulty is in obtaining photosensitive materials of high optical quality and sensitivity.

Besides memory systems, the wave photographs of Denisyuk could be used for the following (STROKE, 1969):

a) Representation (projection) techniques, which would create a total illusion of reality of the projected images, e.g. three-dimensional portraits reconstructed by sunshine.

b) Hydro-location, radio-location and ultransonic inspection methods.

c) Preparation of dispensing elements of the volume diffraction grating type - modelling of three-dimensional gratings in crystallographic investigations.

4.3. Recognition

There are a number of practical systems based on the image recognition properties of holograms. Up to now it has been assumed that the reference beam was a point source. If the reference beam is a spatially coherent extended source, then the resolution of the image-forming process is reduced because of the spreading or smearing of the image object point - it introduces a convolution term into the analysis. However, Stroke and Restrick (1965) showed that the loss of resolution which would result from the recording of a hologram with an extended source could, paradoxically, be retrieved in the reconstruction by illuminating the hologram also with an extended source, provided that the correlation function of the two suitably structured sources had a narrow central peak, of a width comparable to the resolution limit sought in the two step process. Thus it is possible to record a large number of variants of handwritten letters along with the machine code for every letter (GABOR, 1965). Recognition would be indicated by the appearance behind the hologram of the maximum signal, in a form of a set of bright points - the machine code of the given letter.

There are two aspects to pattern recognition:

a) to recognize a particular pattern, from a large number of patterns

b) to assign a particular pattern to one of a number of generalized classes of patterns.

The first can be made a sub class of the second by assigning each of the patterns in a collection to a general class, and recording those patterns which are of a particular type. The alternative is to compare each pattern with the class being sought, and rejecting those which do not belong to it. This can be done optically by using a hologram as a matched filter, i.e. only allowing to pass those patterns with certain characteristics. Now (b) can be considered as a subset of (a) in that the recognition of a particular image is carried out by a series of optical filters.

In order to prevent the changes in the hologram whenever the letter is translated, Gabor (1965) proposed the utilization of the Fourier transform, i.e. a hologram obtained in the focus of a lens, or alternatively, a Fraunhofer hologram prepared in the far field (LOHMANN and ARMITAGE, 1964).

4.4. Other Physical Representations of Holographic Behaviour

An optical hologram has the ability to handle a vast amount of information, which is why it exhibits such interesting phenomena, but this can lead to difficulties in seeing the underlying principles involved, and there are other simpler physical representations utilizing the holographic principle. Lonquet-Higgins (1968) proposed, for example, a bank of resonators, the k^{th} one of which would have a resonant frequency ν_k separated from each of its neighbours by μ. Given certain conditions, this bank would behave in a similar manner to a hologram.

Simplifying even more, one could consider the action of one such resonator. Such a resonator could be a weight on a spring in a viscous medium. If this weight was displaced, there would be a retarding force proportional to the extension of the spring, i.e. the distance of the weight from the equilibrium position and a retarding force, due to the "friction" as it travelled through the viscous medium, which would be proportional to the velocity of the weight. Thus the force acting on the weight was $-kx - \alpha v$ where x was the distance of the weight from the equilibrium position, v was its velocity at that point, and k and α were constants. Now $v = \frac{dx}{dt} = \dot{x}$, So this force can be expressed in terms of the mass of the weight and the acceleration ($a = \frac{dv}{dt} = \frac{d}{dt}(\frac{dx}{dt}) = \ddot{x}$) imparted to the weight.

Thus,

$$M\ddot{x} = -\alpha\dot{x} - kx \quad \text{OR} \quad M\ddot{x} + \alpha\dot{x} + kx = 0 \qquad 4.4.1$$

Given this system, then, there was no movement until the weight was displaced and released. When this happened the weight travelled back to the equilibrium position and, in fact, generally overshot, the forces which originally were accelerating it to the equilibrium position then decelerated the weight until it stopped and then the weight was accelerated back to the equilibrium position again. This oscillation generally died down over a period of time and the weight came to rest at the original position. If the medium in which this experiment was carried out was very viscous the weight would not oscillate but slowly return to the equilibrium position.

The solution to the above differential equation (4.4.1.) is of the form,

$$x = e^{pt}$$

where $p = -\nu \pm (\nu^2 - \omega_0^2)$

where $\nu = \alpha/2M$ and $\omega_0 = (k/M)^{\frac{1}{2}}$ and is the undamped frequency.

If ν^2 is greater than ω_0^2 ($\gamma^2 > \omega_0^2$), then the general solution is

$$x = \tfrac{1}{2}Ae^{-(\gamma + (\nu^2 - \omega_0^2)^{\frac{1}{2}})t} + \tfrac{1}{2}Ae^{-(\gamma - (\nu^2 - \omega^2)^{\frac{1}{2}})t}$$

where A and B are arbitrary constants. Thus the displacement tends exponentially to zero in the highly damped case.

If ν^2 is smaller than ω_0^2 ($\nu^2 < \omega_0^2$), then $p = -\nu \mp i\omega$ where $i = (-1)^{\frac{1}{2}}$

and $\omega = (\omega_0^2 - \nu^2)^{\frac{1}{2}}$.

Thus,

$$x = \tfrac{1}{2}Ae^{i\omega t - \nu t} + \tfrac{1}{2}B^{-i\omega t - \nu t}$$

$$= R_e(Ae^{i\omega t - \nu t}) \quad \text{i.e. the real part of } Ae^{i\omega t - \nu t}$$

$$= ae^{-\nu t}$$

where $A = ae^{i\epsilon}$, and $B = ae^{-i\epsilon}$.

which represents an oscillation with an exponentially decreasing amplitude $ae^{-\nu t}$, and an angular frequency ω, less than that of the undamped oscillator.

The weight need not, however, be simply released, a force could, for example, continue to act on it. If this force was constant, i.e. gravitation in the above example, the equilibrium position is changed, the spring has a certain extension at equilibrium. Switching on and off power supply lines in an electrical system is another example. Suppose, however, the force is periodic in time, with the simple form,

$F(t) = F_1 \cos w_1 t$, where F_1 and w_1 are constants. As $\exp(iwt) = \cos wt + i \sin wt$ which can be divided into Real ($\cos wt$) and Imaginary ($\sin wt$) parts, $\cos w_1 t$ can be represented by the Real part of the solution $\exp(iw_1 t)$ and thus the solution, x, to the differential equation is the real part of the solution, z, of the following equation:

$$M\ddot{z} + \alpha \dot{z} + kz = F_1 e^{i\omega_1 t}$$

Now in the case where the damping is less than the critical value i.e. $(\nu^2 < \omega_0^2)$ then $x = a_1 \cos(w_1 t - \theta_1) + ae^{-\nu t} \cos(wt - \theta)$ 4 4.2.

$$\text{where } a_1 = \frac{F_1/M}{[(\omega_0^2 - \omega_1^2)^2 + 4\nu^2\omega_1^2]^{1/2}}$$

$$\text{and } \tan = \frac{2\nu\omega_1}{\omega_0^2 - \omega_1^2}$$

The second term in the general solution, which represents a free oscillation, does away exponentially with time, and is therefore called the "transient". After a long time, the displacement x will be given by the first term, thus, no matter what initial conditions are chosen, ultimately the oscillations are governed by the external force, with a period of the applied force.

If the period of the applied force, w_1, is the same as the unforced period then the amplitude, a_1, is :

$$a_1 = \frac{F_1}{2M\nu\omega_1} = \frac{F_1}{\alpha\omega_1}$$

which can be very large if the damping constant α is small, and the system is said to be in resonance. The maximum will actually occur at a frequency w_1 slightly lower than w_o, namely:

$$w_1^2 = w_o^2 - 2\nu^2$$

however, if γ is small this does not vary much from w_o.

The physical picture of this is the pushing of a child's swing. If the force (the push) is inserted at the same point in the swing once every period of the swing, the amplitude will become larger and larger. It should be noted that the force need not be applied when the swing is going away from the pusher. If it is initially applied when the swing is on a downward path, the effect is at first to decelerate the swing until the force and the swing are in phase, and then the amplitude of the swing increases. This is equivalent to the transient term of 4.4.2. At points away from resonance the amplitude will be small. If, for example, the pusher applied the force at twice the frequency of the swing, the accelerating force applied in the upswing would be cancelled by the retarding force applied in the downswing. Note, however, that if the period of the force is a lower harmonic of the period of the unforced oscillator, there will be a build up of amplitude, provided that the damping was small enough so that the oscillation had not died away in between the impulses. This is because the pusher is not providing the simple periodic force assumed by the above calculation.

To be a simple periodic (i.e. of one frequency) oscillation, the oscillation has to a sine or cosine waveform existing from $-\infty$ to $+\infty$. Thus, if an atomic particle is regarded as a wave, whose frequency defines its momentum, then this wave would have to be infinitely long for this momentum to be defined uniquely, making the definition of its position uncertain. Infinity, however, is theoretical and a waveform can be regarded as of a single frequency when the oscillator has settled down, i.e. the transients in eqn. 4.4.2. are no longer significant.

It is now possible to define the frequency of a periodic oscillation. Thus, the frequency of a sinusoidal wave is defined by an expression such as sin wt. Thus, if a pen is fixed to an arm which is rotated at a constant angular velocity, the pattern recorded on a sheet of paper moving with constant linear velocity would be sinusoidal. Similar results would be obtained if the pen was coupled to a system exhibiting simple harmonic motion. The important point in this definition is that the frequency thus defined is not only a function of the period of the waveform but also its shape, thus a series of pulses could be said to have a periodicity of x pulses per second, but this is not the frequency of the pulse train. This distinction is not just academic but is crucial to the following analysis.

Given the above definition, it seems that it is rather limited. Objects do not rotate at constant angular velocities, they usually start from rest, accelerate, decelerate and stop, s.h.m. oscillations decay. What is required is a method whereby a non sinusoidal oscillation can be analysed in terms of sinusoidal waveforms, and then it will be possible to talk about its frequency as opposed to its periodicity. The first thing to note is that, though its periodicity is a single valued function, its frequency is not necessarily so - the only kind of wave that can have a single valued frequency is a sinusoidal one, in which case it equals its periodicity.

A non sinusoidal periodic waveform can be represented by the following series (Fourier),

$$f(x) = \tfrac{1}{2}a_0 + a_1 \cos x + a_2 \cos 2x + \ldots\ldots + a_n \cos nx + b_1 \sin x + b_2 \sin 2x + \ldots\ldots + b_n \sin nx \qquad 4.4.3$$

where f(x) is a periodic function, i.e. $f(x + 2\pi) = f(x)$ and a and b are the amplitudes of the various harmonics.

Thus:

$$f(x) = \tfrac{1}{2}a_0 + \sum_{n=1}^{\infty} (a_n \cos nx + b_n \sin nx).$$

The range of interest is $0 - 2\pi$, i.e. the pattern is repeated every 2π distance along the x-axis, and to find the value of the constant a_0, all that needs to be done is to integrate both sides with respect to x (a_0 is the average value of the function), as $\int_0^{2\pi} \sin nx\,dx = \int_0^{2\pi} \cos nx\,dx = 0.$

$$\therefore \quad a_o = \frac{1}{\pi}\int_0^{2\pi} f(x)\,dx$$

To find a_n multiply both sides by cos mx and then integrate with respect to x then $\int_0^{2\pi}\cos nx\cos mx\,dx =$ 0 except when m = n, then it equals π

$$\int_0^{2\pi}\cos mx\sin nx\,dx = 0.$$

$$\therefore \quad a_n = \frac{1}{\pi}\int_0^{2\pi} f(x)\cos nx\,dx.$$

Similarly $b_n = \frac{1}{\pi}\int_0^{2\pi} f(x)\sin nx\,dx$

Consider a square wave of the form $0<x<\pi$, f(x) = 1 and $\pi < x < 2\pi$

f(x) = -1

$$a_o = \frac{1}{\pi}\int_0^{2\pi} f(x)\,dx = \frac{1}{\pi}\left(\int_0^{\pi}(1)\,dx - \int_{\pi}^{2\pi}(1)\,dx\right) = 0$$

$$a_n = \frac{1}{\pi}\int_0^{2\pi} f(x)\cos nx\,dx = \frac{1}{\pi}\left(\int_0^{\pi}\cos nx\,dx - \int_{\pi}^{2\pi}\cos nx\,dx\right) = 0$$

$$b_n = \frac{1}{\pi}\int_0^{2\pi} f(x)\sin nx\,dx = \frac{1}{\pi}\left(\int_0^{\pi}\sin nx\,dx - \int_{\pi}^{2\pi}\sin nx\,dx\right)$$

$= \frac{4}{n\pi}$ when n is odd and = 0 when n is even

$$\therefore \quad f(x) = \frac{4}{\pi}\left(\sin x + \frac{1}{3}\sin 3x + \frac{1}{5}\sin 5x + \frac{1}{7}\sin 7x \ldots\right)$$

Thus, the wave consists of a fundamental frequency (= periodicity) and a large number of harmonics, the more of these harmonics that are plotted, the more accurate the synthesized waveform will represent a square wave. Thus, the square wave can be plotted not only as a square wave on a graph of amplitude versus distance (or time), but as a series of vertical lines on a graph of amplitude against frequency. Thus, if another harmonic was added to the waveform (it would have to be a harmonic or the periodicity would be upset), then the new wavefront need not be drawn by calculating the new envelope point by point in a spatial plane, but by simply adding another vertical line of appropriate amplitude in the frequency plane.

However, the above analysis is limited to periodic waveforms, the most usual patterns are non-periodic and unique.

Consider a function with a period of $2l$ in which f(x) = f(x + $2l$) i.e. the wavelength of the function is $2l$

$$f(x) = \tfrac{1}{2}a_0 + \sum_{n=1}^{\infty} a_n \cos\frac{n\pi x}{l} + \sum_{n=1}^{\infty} b_n \sin\frac{n\pi x}{l}$$

as $e^{\frac{in\pi x}{l}} = \cos\frac{n\pi x}{l} + i\sin\frac{n\pi x}{l}$

4.4.3. can be written as:

$$f(x) = \sum_{n=-\infty}^{\infty} d_n e^{\frac{in\pi x}{l}}$$ where $2d_n = a_n - ib_n \; (n \geq 0)$

and $2d_n = a_n + ib_n \; (n < 0)$

To find d_n, as before, i.e. multiply both sides by

$$\int^{l} e^{-\frac{im\pi x}{l}} dx$$

Therefore $$\int_{-l}^{l} e^{-\frac{im\pi x}{l}} f(t)\,dt = \sum_{n=-\infty}^{\infty} d_n \int_{-l}^{l} e^{i(n-m)\pi x/l} dx.$$

$$\int_{-l}^{l} e^{i(n-m)\frac{\pi x}{l}} = 0 \qquad m \neq n$$

$$= 2l \qquad m = n$$

$$\therefore d_n = \frac{1}{2l}\int_{-l}^{l} f(x) e^{-\frac{in\pi x}{l}} dx$$

Let $2l = 2\pi\lambda$

Then $$d_n = \frac{1}{2\pi\lambda}\int_{-\pi\lambda}^{\pi\lambda} f(x) e^{-\frac{inx}{\lambda}} dx$$

i.e. $$f(x) = \sum_{n=-\infty}^{\infty} \frac{1}{2\pi\lambda}\int_{-\pi\lambda}^{\pi\lambda} f(x) e^{-\frac{inx}{\lambda}} dx \, . \, e^{\frac{inx}{\lambda}}$$

Now if $\frac{n}{\lambda} = \alpha$, and $\frac{1}{\lambda} = d\alpha$, and λ is allowed to become infinitely large, i.e. a pulse which will not be repeated in a finite period, as $\lambda \to \infty$, then $d\alpha \to 0$ and $\sum_{n=-\infty}^{\infty} d\alpha \longrightarrow \int_{-\infty}^{\infty} dx$

and so

$$f(x) = \frac{1}{2\pi}\int_{-\infty}^{\infty} \{f(x) e^{-i\alpha x} dx\} e^{i\alpha x} d\alpha$$

writing $\int_{-\infty}^{\infty} f(x) e^{-i\alpha x} dx = F(\alpha)$

then $f(x) = \frac{1}{2\pi}\int_{-\infty}^{\infty} F(\alpha) e^{i\alpha x} d\alpha$ which is the Fourier transform for a single pulse. In a similar manner as a continuous square wave can be represented in the frequency domain, a single square pulse can also be so represented.

e.g. a square wave represented by $f(x) = \begin{cases} 1 & |x| < a \\ 0 & |x| > a \end{cases}$

Its Fourier transform is:

$$F(\alpha) = \int_{-\infty}^{\infty} f(x) e^{-i\alpha x} dx = \int_{-a}^{a} (1) e^{-i\alpha x} dx$$

$$= \left[\frac{e^{-i\alpha x}}{-i\alpha}\right]_{-a}^{a} = \frac{e^{i\alpha a} - e^{-i\alpha a}}{-i\alpha} = 2\frac{\sin\alpha a}{\alpha}$$

When

$$\alpha = 0 \qquad F(\alpha) = 2a$$

This is also the amplitude distribution of Fraunhofer diffraction from a square aperture in optics.

Returning to the original concepts introduced in this section, a system exhibiting harmonic motion can be of many types, i.e. the equation for an electrical system, for example, is:

$$L\ddot{q} + R\dot{q} + \frac{1}{C}q = 0$$

Where L is the inductance of the system, R is the resistance, C the capacitance, q the charge in the circuit. The system could equally well be a fluid or thermal one. It is now conceivable that such systems could act as resonators and could be made to be very selective as to the type of force that would cause resonance. Thus, a sinusoidal signal could impinge on one such resonator but, unless the frequency of the signal was correct the resonator would not oscillate (if the frequency was correct the resonator would oscillate). If such a system formed part of an interface between two other systems, only a given frequency would be allowed through; the interface would then be equivalent to a filter. A hologram is such a filter. The various points on the interference patterns can be regarded as point resonators which, when excited by a signal of the appropriate frequency, will become point oscillators and will form a new wavefront, which will recreate the image. The signal need not be a sinusoidal wave - if it is a non-sinusoidal wave it would have to have a harmonic with sufficient amplitude to cause the oscillator to resonate. It is possible now to imagine a bank of such resonators which could be constructed so that, on inputting a certain signal into the bank, certain of the resonators will oscillate and others will not. Those resonators which oscillate need not be in phase with each other, but must have a constant phase difference with the input signal (it is this phase difference which causes the distinctive wavefront in the holographic reconstruction process). This phase difference is caused by the different distances between points on the hologram, and forms the reconstructed image along the direction of the reference beam. Further, suppose that the resonant frequency and relative phase of these oscillators were fixed by some form of interference of a signal which was to become the output signal for a given trigger signal. This could be done, for example, by an electro-chemical deposition of a conducting material to alter the resistance of capacitance of an electrical circuit. Thus, on receiving the trigger signal, the appropriate output signal would be obtained. Whether such a filter is a memory or pattern recognition machine is hypothetical, it acts as both. The question is whether such a device has advantages over any other similar device. The main property of this device is that it works in the frequency domain, which means that it carries out a Fourier transform on the input signal. This would enable the input signal to be transmitted as a spectrum of the frequencies of the input signal. The amplitude of a line in this spectrum is related to the other lines by a function generated by the input signal and in the limiting case of an infinite number of resonators the function would be represented by a continuous curve. As these resonators are discrete a continuous curve will never be generated. Thus the larger the numbers of resonators the greater the resolution, but the pattern could be recognized from quite a small number of resonators. Secondly, it would be possible for the device to normalize the output, e.g. by assigning values to the amplitude of the harmonics, to represent its percentage value of the maximum amplitude recorded, thus making its recognition of an input signal independent of the size of the input signal. Thirdly, if there were a large number of such resonators diffusely scattered, the output would be independent of the position of the input signal.

4.5. Application of Holographic Techniques to Human Memory

The most startling feature of human memory is the large storage capacity it has compared to conventional computer systems. In fact the most startling feature of any living system is the large storage capacity needed to be carried from one generation to another to enable a new individual to be formed. Thus, the genetic structure in any cell carries an enormous amount of information comparable, perhaps, to the information carried in the brain. Thus, it is not surprising that a system capable of storing the information needed to construct a new individual in one cell would find the storing of the information generated during life in 10^{10} cells very simple. Could such a storage system be made available to the brain in order to carry out its cognitive duties? If such storage depends on the alteration of the molecular structure of the gene, this can be conceived as changing the wave pattern of that molecule. Such a method of storage could be considered as an elementary holographic storage cell. This is analogous to the changing of a particular fringe pattern on the holographic photographic plate. The genetic memory is a read only memory, which is desirable from the point of view of the reproduction of the species. A very stable memory is required which cannot be tampered with very easily. Could such a system form the basis for a cognitive system in the brain?

Consider the amoeba, which is a single celled animal but it exhibits general animal behaviour, i.e. it responds to changes in light, temperature, acidity in the water of its environment, and so on. Its genetic structure contains not only the details or blueprint of its physical structure, but to a large extent contains also the responses to stimuli. Thus, the amoeba can be regarded as an animal system in miniature and, like its larger brothers, digests its food, moves, reproduces itself, excretes its waste, and so on. Does it also show, if in a somewhat primitive way, a process which can be related to cognition, as its other animal functions can be related to functions in higher animals? In other words, when an amoeba moves away from an area of high acidity, is it demonstrating a function equivalent to that one could expect from a primitive nervous system? Even if it is a reflex action of the type of a thermostat, it is still a remarkable thermostat in that the number of stimuli it will respond to compared to its size is considerable. If an amoeba does demonstrate such a cognitive facility, then the human brain cell can be considered as a primitive cell modified in the same way as other specialized cells. The amoeba, of course, lacks the requisite variety to be considered as acting in a free manner, but a large number of such amoeba cells, each only having a few degrees of freedom, would have a very large amount of variety. This, with possibly some randomizing mechanism, could lead to the system acting as a free agent, as described in the introduction. The amoeba has in fact little, if any, freedom of action as most of its reactions are hard wired into its genetic structure. In higher animals the cells, especially the specialized cognitive cells, could have spaces on this structure, or modified genetic protein molecules, which are capable of being altered during the life of an individual. The amoeba might indeed have such spaces, but its one or two would be heavily outweighed by the hard wired centres of action. The amoeba, although it is a single celled animal, demonstrates all the basic functions of higher animals, the only difference is that in multicellular animals, although all the cells are essentially the same, particular cells exaggerate certain functions. Thus, even though all cells digest their food, certain cells in the neighbourhood of the alimentary canal specialize in digesting the food eaten by the animal, and do this at the expense of all their other functions. Other cells, such as muscles, exhibit other specialization, but again the basis for this specialization can be seen in such animals as the amoeba. The suggestion is that like other specialized cells, brain cells have their functions mirrored in the amoeba. This would imply that memory is brought about by reactions within the cell, either by the alteration of the protein structure of the cell, or by using a memory centre that is available in the primitive cell which is its genetic structure. Thus, when a particular cell is in a particular situation, i.e. in the brain, the memory function of the cell is exaggerated at the expense of other functions. This memory would be at the molecular level of the cell. It must be remembered that though the amoeba carries a large amount of information, the information is in such a form that, unlike Leibnitz's monads, the amoeba interacts with its environment, so that both its internal and external states determine its action. While this is so, there is always the possibility of learning. Thus, it could be argued that there is nothing in higher animals that is essentially different from an amoeba, i.e. all the functions of higher animals can be traced back to the structure of an amoeba. It is all a question of emphasis in the higher animals.

Even if it could be shown that a memory could be laid down at a molecular level, and this memory was holographic, there still are difficulties associated with such an analogy. Such a memory could be a volume hologram and read in a manner like that employed in crystallographic investigation, where the crystal structure acts as a deffraction grating for x-rays. In the memory case the deffraction grating will be continually changing. The difficulty, however, is that no wave of a wavelength comparable with light, let alone x-rays, has ever been recorded within the brain. The principal waveforms found in EEGs, for example, are:

DELTA	0.5 - 3.5 Hz
THELTA	4 - 7 Hz
ALPHA	8 - 13 Hz
HIGHER FREQUENCIES (BETA)	14 - 30 Hz (WALTER, 1953).

These waveforms need not, of course, be the waves that record and read the information in the memory store, they could be timing pulses or gating pulses, etc. The above waveforms, assuming the wave velocity in the nervous system is about 3 m/s, would mean that even the shortest wave had a wavelength of about 10 cms. If one bit of information was stored in 100 cc, the brain would have very little storage capacity. To enable the information to be stored at a molecular level, taking into account the slow wave velocity, a wave with a frequency of about 10^8 Hz, i.e. microwave frequencies, would be required. It is not inconceivable that the molecules themselves could be emitting radiation in a similar way to a sodium lamp, i.e. by the relaxation of an excited electron to a stable energy level. Wiener (1961) suggested that the process whereby genes and viruses reproduce themselves is by frequency pulling the material of the new gene so that the frequency pattern of its molecular radiation is the same as the original, in a way similar to the frequency pulling to a stable condition of two electrical generators in parallel. He also suggested that such substances may emit electro-magnetic radiation in the infra-red region. This, of course, has not been proved.

Grey Walter (1953) talks about a possible memory system in which an electrical oscillation dies away in a period of minutes or hours. It is easy to make a model of such a system, all that is needed is a pendulum. The attraction of such a theory is that oscillating circuits have been imagined, and some think identified, in the brain - certainly there are oscillations in EEG records. The advantage of such a memory is that memories can be evoked by memories which have similar frequencies. Grey Walter describes the effects of rhythmic stimulation with light. In some patients, in states of mental strain, a frequency of flicker can be found at which overpoweringly vivid memories of past experiences appear. The frequency of stimulation is often most critical. "At 18 flashes per second, perhaps, the patient is overcome with a memory and the brain is almost convulsed with electrical discharges; at 18.5 flashes per second the tempest abates; at 19 all is quiet".

It thus appears that there are two systems, the optical holographic system and the human brain, which appear to have the same outward behaviour, which suggested that they are analogous. However, they appear to have entirely different mechanisms. It appears that it is possible to obtain most of the characteristics of the brain by linking a hologram to a computer. A computer can, in fact, produce a hologram. The other advantage of considering memory as a hologram is that it enables the processing of data by the brain to be analysed in terms of conventional electronic communication theories.

A possible solution that presents itself is not to consider the actual signals, but the effect of these signals on the total structure of the brain. The signals from adjacent nerve fibres, for example, could interact outside the nerve fibre, but inside the brain structure, to form standing waves. If these standing waves alter the electrical characteristics of the medium, thus affecting the transmission of the next signal, the system could be said to be a memory system. The question is how such standing waves would be recorded.

Holograms can be formed in non-coherent light by splitting the input signal in two, altering the phase of one signal and then causing the two signals to interfere. An input signal to the brain on its passage to the specific position in the brain that deals with that type of signal, triggers off a non specific signal in the reticular formation which floods the brain. The general theory of this signal is that it lowers the threshold of the brain cells, thus allowing the cell to react to a signal of small value - this is the basis of attention. Luria (1973) states that the reticular formation is directly concerned, not only with the maintenance of this optimal cortical tone, but also with the creation of the necessary conditions for the retention of traces of direct experience. This is based on clinical studies of patients with brain damage.

The problem of wavelength still applies, however. The brain is usually considered as a chemical computer. Thus, the purpose of the input signals could be to trigger the release of chemicals in the brain cell which, when considered on a wave mechnical model, might provide the basis for a holographic memory in the brain.

Even if the brain proves not to be based on the holographic principle, the hologram might still prove to be useful as a prediction device and so provide a method of predicting the future states of a time series.

Chapter 5

TIME SERIES AND PREDICTION

5.1 Introduction

As an example of the use of a time series for prediction, consider the case of the gas industry. Gas is distributed through networks or grids consisting of two or more systems: one system, charaterized by a small number of large mains carrying gas at high pressures, which distributes gas from area to area, and the other, characterized by a large number of small mains carrying gas at low pressures, which distributes gas within an area to the customers. The connection between the two systems is through a pressure reduction station (P.R.S.) which, as its name implies, reduces the pressure of the gas from that convenient for distribution to that suitable for domestic use. These P.R.Ss are capable of being operated automatically with the use of instrumentation linked to a central computer. This instrumentation can also be used to register the amount of gas being consumed in a given area. Also within a region covered by a gas board, there is plant for manufacturing gas and facilities for storage. The aim of the system is to match consumption with supply and then to generate a strategy which will do this in the most cost-efficient way. The following paragraph consists of a description of a particular grid system, namely that of the South Eastern Gas Board (Segas).

The data from the P.R.Ss in the gas distribution grid is transmitted by telementry (G.P.O. line) to a small special purpose computer at the Regional Headquarters at Croydon. This data is then presented in a suitable form to the operators in the control room, where it forms the basis of decisions on the required amount of gas to be manufactured. A further small computer, called a translation computer, converts the data, which is in machine code, into a Fortran form so that it can be fed into a larger computer where it will be used in a grid control programme. This part of the system is in its infancy but it is hoped that by using all the data of a past six week period, accurate weightings can be given to factors determining the future consumption of gas. At the present moment calculations for the predicted demand are carried out using models of previous gas demands, a particular type of model being chosen for that day by the operator, mainly on the grounds of experience. This constitutes a man machine interface. Thus, the computer, given the values of various weightings and the sort of demand foreseen, calculates the total demand that might be expected. From this expectation the control room staff can arrange for production to cover that demand. The object is to produce the gas economically. As some plant produce gas cheaply but requires a long response time, whilst others produce gas quite expensively but have a short response time; planning is needed for the proper use of resources. The main object is the survival of the system as the system can "die" if too little or too much gas is produced.

The above system constitutes a manual control system as opposed to an automatic one as defined by Kelley (1968). A manual control system for Kelley was characterized by the adjustment of the parameters of the system according, not to the present departure of the system from a predetermined reference state, but in accordance with a predicted error from the desired state at some future time if no action was initiated, e.g. a driver will be more concerned with the final position of his car, when negotiating a corner, than keeping the car a particular distance from the kerb during the manoeuvre. Thus, the essential difference is the use of the feedforward process in manual control, whereas automatic control uses solely feedback. For feedforward to work it is necessary to have a model, which could be adaptive, of the system and its interaction with the environment, so that predictions as to outcome of various actions can be made. As well as this model a mechanism is required that will calculate the outcome at a rate faster than the response needed in the real world, so that a number of possible strategies can be tried and the most efficient used. The reason why Kelley terms this kind of control as manual is because he feels that only a conscious being is capable of making the choice of which strategy to be used. A computer, he argued, would only choose an action which it considered as efficient only in terms of criteria programmed into it by a human operator, and for him this was a misuse of the term "choose". It would seem to be at least arguable, however, that human beings, also, only choose actions in terms of the needs of their fabric and conditions imposed by society and the environment, and so are incapable of choice in the above limited sense. This is not to make the human being into a purely deterministic mechanism because the complexity of interactions involved make such terms meaningless. Freedom is an equally meaningless term except if freedom is taken in the sense of the ability to generate enough strategies, so that the needs of the fabric can be obtained in all circumstances. Nor does the calling of systems capable of choice as "living" systems deny the possibility of constructing such a system, as the term "living" is used in a different sense to the term "living" used in the sense of living creatures are natural (as opposed to artificial, or man made creatures, i.e. robots).

Kelley (1968), however, was in no doubt that a large amount of a manual control system can be automated, leaving the human operator to plan the overall strategy of the system, i.e. to choose which of a particular set of goals the system will control towards. The main element of such a controller would be a fast-time predictor - a device with which predictive information was generated by an analogue of the system to be controlled, operating repetitively on an accelerated time scale, taking the present values of the system parameters as the initial conditions. The advantage of this combination of feedforward and feedback is that it introduces into the system degrees of freedom. (The term degrees of freedom is used as a neutral term as opposed to pure freedom. It also enables systems to have attributed to them one or two degrees of freedom as in a simple controller, or a large number of degrees of freedom as in a human being.) This is a shift of emphasis from traditional cybernetics with its accent on feedback mechanisms, and possibly reflects a change from considering the living system in terms of machines to the consideration of machines in terms of living systems.

For feedforward control to be possible there must be some form of model available for calculating the possible outcome of events. In the case of gas demand the model is a graph of the variation of gas demand during the day. As these variations can be different for different days of the week, and different weeks in the year, there are a number of such models available. The task is to discover if the generation of such models can be mechanised, and having generated such models, can the outcome of a number of possible strategies be calculated quickly enough so that the "best" one is employed in the real life situation. Because of the nature of the problem, some kind of extrapolator of statistical time series is required and, as such, cannot be expected to produce the ultimate "best" action, but only to improve with time. It has been suggested (PRIBRAM, 1971) that because of the apparently inhibitory nature of the outputs of the cerebellum, a comparison between orders from the motor cortex and a model of movement was carried out in the cerebellum to enable the animal to take appropriate actions in given situations. It has also been suggested (PRIBRAM, 1971) that such systems employ both analogue and digital techniques.

5.2 Time Series

The models used in prediction are usually divided into two classes. The first concerning those phenomena which can be predicted with certainty - deterministic functions of time. For example, in the majority of electrical engineering calculations it is convenient to assume that the most important features of the supply voltage can be represented by the cosine function

$$x(t) = a \cos (2\pi f_o t + \phi)$$

where f_o is the supply frequency and a is the voltage amplitude.

If more accurate measurements were made of the output of the turbo-alternator, it would show that the output is not constant but fluctuates with time in an apparent random manner. However, when the statistical or average properties of this second type of model are studied, similarities with the deterministic function emerge. The new series is a stochastic process and a large amount of theory has been developed to analyse stochastic time series. (Although the variable is usually written as t and interpreted as time, there is no reason why this variable cannot represent other physical qualities, such as space.)

Since different sections of a time series resemble each other only in their average properties, it is necessary to describe these series by probability laws or models. Thus, possible values of the time series at a given time t are assumed to be described by a random variable X(t) and its associated probability distribution. The observed value of x(t) of the time series at time t is then regarded as one of the infinite of values which the random variable X(t) might have taken at time t.

The behaviour of the time series at all times can be described by a set of random variables (X(t)) where the time variable t can take any value from $-\infty$ to $+\infty$. Thus, the statistical properties of the series are described by associating probability distribution with any set of times t_1, t_2, ...t_N. The ordered set of random variables (X(t)) and its associated probability distributions is called a stochastic process. The observed time series x(t) is thus regarded as one of the doubly infinite set of functions which might have been generated by the stochastic process. The set is doubly infinite because an infinite set of values is possible at any time and there are an infinite number of points. Time series may be either discrete or continuous.

A distinction can be made between time series as to whether the data is obtained from planned experiments or the data is non-experimental. Time series in economics and social sciences are examples of non-experimental data. The economist is usually in a position where he can only observe the economic system and is rarely in a position to carry out planned experiments. A further difficulty associated with the analysis of economic time series is that they usually contain few observations. Therefore, it is exceedingly difficult to check whether a given stochastic model provides a good fit to the data. Nevertheless, the techniques of time series analysis are of considerable importance in the analysis of economic data (GRANGER, 1964).

On the other hand, in engineering and the physical sciences, the time scale over which useful data has to be collected is much smaller, so time series containing many more values can be obtained. Furthermore, it is possible to repeat experiments under similar sets of conditions so that the validity of the analysis and of different models can be checked.

As stated above, the stochastic process, from which the observed time series is being generated, can be described by the probability distributions associated with all possible sets of time points. To infer the nature of a series is an impossible or even meaningless exercise. However, it has been found that there are certain assumptions that can be made to make the analysis of observed time series tractable and yet fruitful.

The most important assumptions made about a time series are that the corresponding stochastic process is stationary, and that a stationary stochastic process may be adequately described by the lower moments of its probability distributions. The lower moments include the mean, variance, covariance function and the Fourier transform of the convariance function, the power spectrum. An alternative approach to the above is to assume that the stochastic process can be adequately described by means of a model containing a few parameters, which may be estimated from the data.

Although it is necessary to assume stationarity to describe a stochastic process by its spectrum, in practice the stationarity assumption does not present a serious problem. This is because the spectrum isolates the contributions in the series which can be attributed to different frequency bands. A non-stationary series is usually characterized by the presence of large power at low frequencies. However, in many practical applications, the information which is of interest may be at higher frequencies. In such cases all that is necessary is to filter off the non-stationary low frequency components and use the residual series for the spectral analysis.

In many problems, such as those where it is required to predict future values of the series, it is necessary to construct a parametric model for the time series. To be useful, the model should be physically meaningful and involve as few parameters as possible. A powerful parametric model which has been widely used in practice for describing empirical time series is the moving average-autoregressive process

$$X_t - \mu = \alpha_1 (X_{t-1} - \mu) + \ldots\ldots + \alpha_m (X_{t-m} - \mu) + Z_t + \beta_1 Z_{t-1} + \ldots\ldots + \beta_L Z_{t-1}$$

where Z_t is a purely random series, or white noise, and μ is the mean level of X_t. The model is physically meaningful since it is the discrete analogue of the familiar linear differential equation used to describe linear systems. The model thus represents time series as the output from a linear system whose input is white noise. By introducing a suitable number of the parameters α and β it is possible, after suitable differencing (BOX and JENKINS, 1970), to fit most empirical time series with a relatively small number of parameters.

The analysis of time series has the basic assumption that though the one analysing the series might not know the mechanism by which a particular process proceeds there is someone, or something that does. Thus, a bad winter can be predicted when the snails bury themselves deeper in the soil, because evolution has equipped them with a sense that can detect a hard winter in prospect. Time series such as the Stock Exchange indeces obviously can be affected by people with privileged information who use it. Even in the non-organic world it could be argued that signs such as the colour of the sky at various times of the day are used because the sky has knowledge that the human can only experience through it. Though science can "explain" the future in terms of principles which in turn can "explain" the future phenomena, in the last analysis science consists of identifying particular events of the system, from which it is hoped the future states of the complete system can be predicted. The gas demand for a distribution system can be considered as such a time series, and there would be in that time series indicators of future changes. For instance, if a cold spell meant that more gas was burnt, there will be people who react more quickly than others so the demand will not change suddenly - there will always be previous indicators in the time series. The problem is to identify these indicators, not only in terms of identifying actual people who respond more quickly than others, but also in terms of the changes in the time series itself, i.e. all spurious changes in the series have to be "filtered" out.

5.3 Prediction and Information Theory

Time series can be viewed as messages transmitted with noise through an information channel. Time series are sets of observed data. By definition, this means that the operations carried out by statisticians on such series are not operations on events in the real world, but the analysis of the channel through which that information is transmitted. Take, for example, a single data recording system consisting of a thermocouple, the output of which is amplified and then recorded on a chart recorder. The resultant time series will vary in some way with the temperature of the environment. This variation will not be a simple linear law, for the response of the system to changes in the environment is governed by such factors as the frequency response, of and delays in, the system and the threshold of the recorder. On top of this the amplifier is only approximately linear, if the output from the thermocouple is so large that the amplifier is saturated, the output from the amplifier will not increase no matter how much the temperature increases. In fact it may well decrease because of damage to the amplifier. Further "random" movements of electrons in the system will generate noise, which will be superimposed on the signal. Finally, if the system is used to control a process, the action will be initiated according to the voltages within the system. As far as the system is concerned it is immaterial how those voltages were generated. In case the reader thinks this analysis is too pedantic, consider the concept of temperature itself. There is no such thing as temperature in the real world, so the physicists say, it is merely a representation of the real world analogous to the electrical voltages of the above system. In fact, the measurement of temperature involves the smoothing and averaging of the energies of atoms and, thus, is a case of the information channel acting as a smoothing filter.

Wiener (1949) has pointed out that the simplest operation which could be performed on a time-series, or message, was that of extrapolating them, or prediction. This prediction, of course, did not in general give a precise continuation of a time series, or message, for, if there was new information to come, this completely precluded an exact estimate of the future. In accordance with the statistical nature of time series, they were subject to statistical predictions. Thus, the estimate was the most probable continuation of the series, or the continuation of the series which minimized some determined quantity known as error.

Sometimes it was necessary to separate the quantity being observed from some corrupted series, i.e. one in which the observed signal had been mixed with another time series. Thus, it was necessary to ascertain, in a statistical sense, what this data would have been like without the contamination. This problem might have been separate but equally it might have been part of a prediction problem. This problem also arose in wave filtering. These two series tended to be of a statistical nature, and while the knowledge of the statistical form of the series would never be complete, i.e. the known series is finite, it was a legitimate simplification to assume that the available information went back much further into the past than the period in the future that was required to be predicted (WIENER, 1949).

The usual electrical wavefilter attempted to reproduce a message "in the purity", when its input was the sum of a message and noise. In this case the measure of the purity of the message was the mean power of its perturbation, and if the apparatus used for filtering was of a linear character, the desired statistical information concerning the noise and message alone would be furnished by their spectrum or periodogram. The extra information required concerning the two together was exactly that which could be derived from their cross-correlation (WIENER, 1949).

While the pure filtering problem was clearly distinguishable from the prediction problem, mixed problems involving elements of both were of great importance. The filter problem, as described, was that in which a message was to be imitated without a time delay. In practical circuit problems, a uniform delay was not undesirable if it was not excessive, and the theory had to be adapted to this fact. Indeed, good filter performance depended on the introduction of a delay. If the delay was negative, the performance suffered, but, on the other hand, the filter became a filtering predictor, which was often a useful instrument (WIENER, 1949).

Thus, it should have been possible to make a synthesis between the study of time series and communication engineering. The most important concept that communication theory had to offer in the study of time series was the use of the complex plane which should have enabled Fourier methods, which were in the repertory of both disciplines as they occurred both in the theory of the periodogram and in the operational calculus, to be used more powerfully (WIENER, 1949).

The prediction of the future of a message could be done by some sort of operator on its past; this operator could be realized by a scheme of mathematical computation, or by mechanical or electrical apparatus. It was found that the ideal prediction mechanisms which were first contemplated by Wiener and his collaborators were beset by two types of error, of a roughly antagonistic nature. While the prediction mechanism first designed could be made to anticipate an extremely smooth curve to any desired degree of approximation, this refinement of behaviour was always attained at the cost of an increasing sensitivity. The better the apparatus was for a smooth wave, the more it would be set into oscillation by small departures from smoothness, and the longer it would be before such oscillations would die out. Thus the good prediction of a smooth wave seemed to require a more delicate and sensitive apparatus than the best possible prediction of a rough curve, and the choice of the particular apparatus to be used in a specific case was dependent on the statistical nature of the phenomenon to be predicted. This interacting pair of types of error seemed to have something in common with the contrasting problems of the measure of position and of momentum to be found in Heisenberg quantum mechanics, as described in his Principle of Uncertainty. Thus, assuming the statistics of a time series, it became possible to derive an explicit expression for the mean square error of a prediction by a given technique and for a given lead, i.e. optimum prediction was the determination of a specific operator which should reduce to a minimum a specific positive quantity dependent on this operator (WIENER, 1948; 1961).

Wiener (1948; 1961) also argued that the transmission of information was impossible, save as a transmission of alternatives. If only one contingency was to be transmitted, then it could be sent most efficiently and with the least trouble by sending no message at all. The telegraph and telephone could perform their function only if the messages they transmit are continually varied in a manner not completely determined by their past, and could be designed effectively only if the variation of these messages conformed to some sort of statistical regularity.

Several writers (SHANNON 1949; WIENER 1948; 1961; KOLMOGOROFF 1941) have developed a statistical theory of the amount of information in a message, in which the unit amount of information was that transmitted as a single decision between equally probable alternatives. Just as the amount of information in a system was a measure of the degree of its organization, the entropy of thermo-dynamics of a system was a measure of its degree of disorganization — the one is simply the negative of the other. Thus, if it was known a priori that a variable lies between 0 and 1, and a posteriori that it lies on the interval (a,b) inside (0,1), then the amount of information gained from the a posteriori knowledge is

$$-\log_2 \frac{\text{measure of } (a,b)}{\text{measure of } (0,1)} \qquad \text{(WIENER 1948; 1961)}$$

or alternatively, the choice of a logarithmic base corresponded to the choice of a unit for measuring information. If the base 2 is used the resulting units could be called binary digits, or bits. A device with two stable positions, such as a relay or a flip-flop circuit, could store one bit of information. N such devices could store N bits, since the total number of possible states was 2^N and $\log_2 2^N = N$ (SHANNON 1949).

However, Shannon's theory dealt only with a communication channel, and not with individual messages, as does Wiener's theory of extrapolation, interpolation and smoothing of stationary time series (1949). Wiener's theory says: "given a certain information channel with a given signal to noise ratio, like a record player for instance, how can one achieve, by filtering, the best signal to noise ratio averaged over all messages which could be sent through the noisy channel in unit time?" This procedure of filtering modified the channel capacity, but it put the power in the frequency band where it did the most good. It, therefore, maximized the channel capacity for a given power level. Van Heerden (1968) argued that Wiener's theory had nothing to say about the situation encountered in real life: "This is my information; what is my rational expectation of the future?"

Finally, Wiener (1961) has also discussed the operative procedure for building self reproducing machines. A machine could be considered as an agency for accomplishing certain definite purposes, and self-propagation was the creation of a replica capable of the same functions. Considering the class of machines known as non-linear transducers it was possible to imitate any unknown member of that class by a sum of linear terms, each of fixed characteristics and adjustable coefficients (GABOR, WILBY and WOODCOCK 1960). Such machines had as input a single function of time and their output another function of time. The output was completely determined by the past of the input, but in general, the adding of inputs did not add the corresponding outputs. If the transducer was to be imitated, the adjustable coefficient could be determined as the average product of the outputs of the unknown transducer and a particular known transducer, when the same shot-effect generator was connected to the input of both. This could be improved by, instead of computing this result on the scale of an instrument and transferring it by hand to the appropriate transducer, thus producing a piecemeal simulation of the apparatus, automatically effecting the transfer of the coefficients to the pieces of feedback apparatus. What was produced was a white box which could potentially assume the characteristics of any non-linear transducer whatever, and then to draw it into the similitude of a given black-box transducer by connecting it to the same random input and connecting the outputs of the structure in the proper manner, so as to arrive at the suitable combination without any external intervention (WIENER 1961). Such a machine has been built by Gabor and his collaborators (GABOR, WILBY and WOODCOCK 1960) and used as a universal predictive filter and simulator.

5.4 Prediction of a Binary Time Series

For the moment a predicting machine can be considered as a black box, or filter, whose input is a time series and whose output is the same time series but leading the input by a given amount. A simple if somewhat trivial example of such a filter is an electrical capacitor; if the A.C. voltage across the capacitor is considered as its input and the resultant current as the output, then the output leads the input by a phase angle of $\pi/2$. To simplify the problem, consider the case when the input signal f(t) is in the form of a binary time series. A binary time series is a sequence of ones and zeros only, in any order, and given at regular intervals of time Δt_o. Though this seems to make the discussion less general, it must be remembered that just as a non-linear time series can be described by a number of linear series, any form of information can be encoded as a binary time series. For instance, the demand of gas from any P.R.S. in the gas grid system $D(t)$ can be encoded into a binary time series $f(t)$ by choosing a standard interval Δt_o and defining $f(t)$ only for the values of $t = k \Delta t_o$, where k is any whole number. If $D(t) > D(t - \Delta t_o)$ then $f(t) = 1$ and otherwise $f(t) = 0$. This function $f(t)$ can then be transmitted and received, and transformed back to a stepwise demand $d_1(t)$ by taking $\Delta D_1 = D_1(t) - D_1(t - \Delta t_o)$ equal to $+ \Delta D_o$ if $f(t) = 1$, and equal to $- \Delta D_o$ if $f(t) = 0$. This can be made to follow the actual demand curve as accurately as desired by making Δt_o small.

Van Heerden (1968), applying Mackay's idea (1956) that intelligence was a striving of a mechanism to come to rest when disturbed by an outside influence (cf. Ashby's homeostat (ASHBY, 1952)), proposed that if the black box could construct from an input series an output series which could be combined with the input so that the resulting series is zero, then this black box would be capable of intelligent behaviour. In the human being the input IS derived from two sources: i) the senses and ii) from the needs of the fabric to survive. Thus, when the organism is hungry, it initiates a series of actions whose aim IS to eliminate this hunger. The brain, however, did not see, hear or feel pain, nor did it speak or write; it merely responded to electrical signals which were meaningless to it, and put out signals the results of which it did not know. Logically, this initial intelligent response could be represented as a circuit connecting input and output outside the black box.

This could be represented mathematically as follows : a new time series h(t) which was the sum of the input f(t) and the output g(t), i.e. h(t) = f(t) $\dot{+}$ g(t). (So that h(t) was another binary time series, the symbol $\dot{+}$ standing for "plus modulo two" and 1 + 1 = 0, 1 + 0 = 1, 0 + 0 = 0). Thus, if the function h(t) could be correctly predicted by some rational means, then g(t) could be chosen so that f(t) is identically zero (VAN HEERDEN, 1968). This also enabled a tentative definition of meaning to be proposed. If an organism understood fully the time series f(t) it was able to predict the future members of that series, or, as f(t) no longer contains any information if it is totally predictable, if it only partially understands the input it would be able to limit the next member of the series to a band of values. The first definition is useful in the case of a single binary time series and the second in the case of a multiple binary time series.

How, given information encoded in a binary time series, is it possible to predict its future in a rational way? As can be seen above the meaning ascribed to any particular time series is arbitrary. To talk about the laws of motion determining the positions of particular planets is simply to say that: in the past it has been possible to predict accurately a time series with a particular pattern, i.e. generate the time series h(t) by an output g(t) which consisted of carrying out on the input certain actions (the mathematical application of the laws of motion - which themselves are merely a time series). Phrases such as the "laws of motion" are just a shorthand way of refering to the particular time series which in the past has generated a correct prediction. When these phrases are read or heard, they are immediately transformed to a binary time series for transmission from the eye, or the ear, to the brain. The reverse happens when the brain formulates an output in response to a particular input - a binary time series is transmitted to the vocal chords, or hands, which results in speech, or writing, and the generation of words and phrases. If the output from the brain was such that the leg muscles were activated, for instance, so that one walked towards a particular object, there would be no confusion as to the ontological status of the signals from the brain and the actual action. This lack of confusion is in no small measure due to the ability to build artificial control mechanisms which do not need the equivalent of a leg-in-the-brain. Thus, the feeling that words and phrases reflect reality, not some internal representation, albeit generated by an interaction with the environment, of that reality, is false. In information theory terms these are differently coded forms of information in different information channels. This coding is in the form of meaningless symbols.

For prediction all there is is the past values of the binary time series and all a rational being can do is carry on predicting the future of the time series by a tried and trusted method until he is proved wrong. As Van Heerden (1968) puts it: "The principle of prediction we have used here is the well known ancient, commonsense principle of induction:

Whatever relation we find to be constant in the past, we expect to be constant in the future. This has always been considered, by scientists, a vague, uncertain and unscientific source of prediction. True, David Hume, the eighteenth century philosopher, reasoned that it was the only source of knowledge but although nobody could disprove his argument (See RUSSELL 1946; VON WRIGHT 1961), he was ignored as patently against common sense. We just feel that scientific knowledge is more realiable than that! Information theory, however, has provided us with an analysis against which vague philosophical protests will no longer do. The very logic of the binary series as the form of information will force us to admit that Hume was uniquely right. The principle of induction is the only source of knowledge, both scientific and commonsense, of the real world".

Returning to the binary time series, Van Heerden (1968) assumed that besides the binary time series f(t) there were a number of other binary time series available, $g_1(t)$, $g_2(t)$ ...... $g_k(t)$. Further, he assumed that if a function $g_j(t)$ matched f(t) over a considerable length of time in the past, then it could confidently be expected that it would continue to match in the future, thus if the future of $g_j(t)$ was known, then f(t) could be rationally predicted. Now in the case of a binary time series, there were always other time series available of which the future was known. These were making, for the sake of convenience, the standard interval Δt_o to equal 1, the series: $g_1(t) = f(t-1)$, $g_2(t) = f(t-2)$ etc. In other words f(t) could be compared with its own past, e.g. f(t) = 1111...., which could be matched with f(t-1), f(t) =

101010...., which matched with f(t-2) and f(t) = 110110110....,
which matched with f(t-3).

The above could be generalized further using the Huffman delay operation D, defined to operate on f(t) such that $Df(t) = f(t-1)$ and $D^k f(t) = f(t-k)$ (HUFFMAN 1955). Also the delay polynominal P(D) defined as follows, was introduced :

$$P(D)f(t) = (C_o + C_1 D = \ldots\ldots C_k F^k)f(t) = C_o f(t) + C_1 Df(t) + \ldots\ldots + C_k D^k f(t).$$

Here + was again "plus modulo two", and the C's were either 1 or 0. If a specific delay polynominal $Psp(D) = D + D^7 + D^{12}$ was constructed, and it was found that Psp(D)f(t) had been matching f(t) for the past 1000 digits, it would be rational to expect that PspD(t)f(t) would continue to match f(t) in the near future (VAN HEERDEN 1968).

Van Heerden (1968) pointed out that care must be taken against the mistake of constructing, ad hoc, a delay polynominal P_{ah}, with coefficients C_k up to k equals the number digits in f(t). At first glance it looks as if P_{ah} was an extremely good predictor, whereas in fact it was no good at all. The coincidence was only significant if P(D) was simple. If a binary code can be developed for delay polynominals the complexity C_k of P(D) could be given as the number of binary digits, the number of bits, required to describe it. An easy and universal way of encoding was to make a list where every item desired had its specified position. Then its code was its rank number in the list. If its rank number was k, then its "complexity" C_k was defined as, $C_k = \log_2 k$. If an operator,

P_k was such that $P_k(D)f(t) = f(t)$ for the past n_k digits, and if the complexity of P_k was C_k bits, then P_k was a good predictor if the "value", V_k, $= (n_k - C_k)$ was large. It was the information reduction that was the significant point (VAN HEERDEN, 1968). This gives a definition of a random series, i.e. a series which cannot be reduced (CHAITIN, 1975).

There is no reason to stay with delay polynominals, which are only linear operators. Consider any operator O operating on f(t), defined as to make out of f(t) any function of f(t-1), f(t-2) etc., and in which also continuous products like $f(t-l_1)$, $f(t-l_2)$, $f(t-l_3)$, are allowed. All the operators which are considered desirable can be encoded. It was particularly convenient to encode by rank number in a list, because it meant that new desirable operators could be added to the list without the need to change the code. If O_k be the general operator with rank number k and complexity $C_k = \log_2 k$ and $O_k\, f(t) = f(t)$ or $(1 + O_k)f(t) = 0$ for the past N_k digits, then $V_k = (N_k - C_k)$ was the value of O_k as a predictor. When good predictors contradict each other, then their value decided which one was the best, and therefore supplied the most rational prediction (VAN HEERDEN, 1968).

It must be realized that the number of different operators that can be constructed for a time series of n digits long is more than 2^n. Even the linear operators, the delay polynominals, are 2^n in number. A time series with a significant amount of information may well be a million digits long. This number of possible operators is, therefore, so large that it will be impossible to ever try them all. For that reason, it is always possible that there will be an operator which is a better predictor. If the time series is extremely simple, like 1010... in that case, the operator $(1+D^2)$ reduces the series to zero over (n-2) digits, and no operator can do any better. Van Heerden (1968) has argued that this left room for invention and discovery.

Van Heerden (1968) stated that a confidence level could be assigned to a prediction. If V_1 was the value of the best prediction in a certain situation, and V_2 was the value of the best predictor which forecasts an altogether different outcome, then the confidence level, cf, was now defined as $cf = \frac{V_1 - V_2}{V_1}$, i.e. if V_2 was very small with respect to V_1, then cf is almost unity, if $V_1 = V_2$, then our confidence in the prediction was zero, as it should be.

Van Heerden objected to the use of probability in these sort of cases as the organism could not know all the possible permutations and, thus, could not assign a true value for the probability. However, it was felt that the concept of probability will be useful, as used by Uttley in his conditional probability machine. Any use of probability in this sense assumed the principle of induction, i.e. the probability distribution in the future will be the same as in the past.

5.5 Realization of a Predicting Filter

It is possible, of course, to make the preceding more general, in that instead of one box there are a number of boxes in series or in parallel. If a binary time series of n digits contains the maximum amount of information, it looks very much like a random series. This is because any regularity spotted implies the existence of an operator which can predict and, thereby, reduce the information. In a random series, the length of a sequence in the immediate past, which matches some other sequence by pure chance, is of the order of $\log_2 n$ digits. It follows that the predicting system $(1 + D^k)$ requires an amount of $n \log_2 n$ elementary binary operations between each two digits. (An elementary binary operation is the simple addition or multiplication of two binary digits– the series has to be compared with all of its n pasts, and each comparison requires of the order of $\log_2 n$ elementary operations.) If a human stores during a life time, on the average one bit per second, then the estimated stored information in the human brain, being of the order of the number of brain cells, may be 10^9 bits, would seem to reasonable. If an artificial intelligent system is to be equal to the human brain it requires, therefore, $10^9 \log_2 10^9 = 3 \times 10^{10}$ elemenatry binary operations per second (VAN HEERDEN 1968).

The reason for discussing artificial intelligence in these circumstances is that the gas demand problem requires that the system partakes in the decisions made on the feed-forward model, i.e. to make the system in Kelley's terms a manual one. It has been stated that the essence of intelligence is judgment, and that judgment is really recognizing, and that recognizing requires the fast and continuously active search through a very large storage of possibly relevant information (VAN HEERDEN, 1968). Although this process can be defined in logical terms and, therefore, can be carried out in principle by a digital computer, the enormous size of the problem makes this fact rather academic. Van Heerden (1968) has designed a machine for carrying out this task using the principle of holography which seemed more suitable for this purpose, and which was probably also physically quite similar to the operation of the brain. Holograms, by analogy with electronic networks, can be considered as optical filters and so be used to process information, "matched filters" in optics could, thus, provide the means for pattern recognition. A hologram can be used as an optical matched filter.

As described in the previous chapter, a hologram is a means of recording the whole information in an optical wavefront emitted from an object. In a photograph only the intensity of the wavefront impinging on the photographic plate is recorded, but in a hologram both the intensity (i.e. the square of the amplitude) and the phase are recorded. This is achieved by illuminating the object with coherent radiation and causing the resulting wavefront to interfere with a reference beam. If a photograph is taken of this interference pattern, and then processed to produce a transparency which is then illuminated with the reference beam, the original wavefront is reconstructed, thus reproducing the object in a three dimensional form.

With a laser, large holograms are possible, which consist of a number of smaller holograms scattered irregularly over the photographic plate, thus, the image is strengthened and so there is more resolution in the reconstructed wavefront. This also means that the image can be reconstructed even when the hologram is broken into small pieces, as long as the piece used for reconstruction contains the whole pattern. The diffusion of the pattern is easily obtained when the object is a solid, opaque one, as the irregularities in the surface cause a scattering of the light, this can lead to laser speckle, the roughness of an apparently smooth surface, to laser light can cause distortion, or noise; but special precautions have to be taken to obtain this diffusion pattern with a translucent object. In this case the object has to be irradiated with diffused light.

Apart from the above properties, the hologram offers the possibility of a memory with a very large storage capacity. Theoretically it appears that it is possible to store one bit of information in a cube with dimensions of about one wavelength. This might be difficult in practice but a density of 300 times the amount stored in conventional microphotography is certainly possible (VAN HEERDEN, 1968). This type of memory is the most analogous to human memory of all artificial systems available. Like the human memory it has a high resistance to destruction. If the principle of holography is made more general other interesting features appear. The conventional hologram is constructed from the interference pattern between a complicated wave and a simple plane or spherical reference beam, the object being reconstructed by illuminating the hologram with the reference beam.

The mathematics of the situation is that of the cross-correlation function. If the reference beam is replaced by another complicated beam (i.e. from a reference object) and if this is forced to interfere with another complicated beam (i.e. from a code) a hologram will be formed. If now the hologram is illuminated with the original beam (i.e. the hologram is shown the reference object) the other object, the code, will be reconstructed. This can be considered as the reference object being transformed into a code that can be recognized by a machine, i.e. pattern recognition. Further, this can be done by using the object beam itself, as long as it correlates sharply with itself, i.e. a complete object can be reconstructed from an incomplete object by means of a hologram. A memory system based on the holographic principle would be an associative one.

As has been noted, the above considerations have led some writers to consider human memory as a special form of hologram. As mentioned before, the mathematics of this process are those of the cross-correlation, which can be treated in terms of transformations (i.e. Fourier transformations) and the convolution equations. Fourier transforms are a method whereby the variation of a quantity with respect to frequency may be found from a given variation with respect to time, or vice versa. A convolution may be simply considered as the operation whereby a structure under observation is smeared, or spread out, by the response or resolution of the instrument or mathematical operation. Pribram (1971) pointed out that responses to visual, auditory and tactile stimuli produced a frequency distribution of the firing of the nerve cell in that particular sense organ, i.e. a Fourier transformation of the input. A hologram can, of course, be constructed from any form of wave phenomena.

Van Heerden (1968) proposed a slightly modified form of recording holograms so that information could be stored in them, and this is shown in Figure 5.1. The information to be stored was originally presented on a transparent slide S in the object plane O. It was illuminated by a parallel light from a coherent light source, like a laser. Consequently, in the image plane, I, an image of S would be seen, faithful within the limitations of the optical system. A photographic plate was exposed, not in I but in the focal plane F, to the light diffracted by S. Such an optical arrangement automatically formed the Fourier transform of the input. This plate, after exposure, was developed and a positive made of it, which was then placed in F. This filter, which had a transmission in each point proportional to the original light intensity, was called hologram, H. If the original slide, S, was arbitrarily divided into two parts S_1 and S_2 and only S_1 was placed in the object plane, then the light from S_1 would be diffracted by H in such a way that, besides the faithful image of S_1, a ghost image of S_2 would appear in the image plane. The smaller the size of S_1, the weaker was the ghost image.

For the purpose of recognition a redundant pattern, a strong point source, P_o, was added to the centre of slide S which contained useful information, with an intensity about equal to the total intensity of the light emerging from the whole of S. This point source P_o had to be coherent with the light source illuminating S, and this could best be achieved

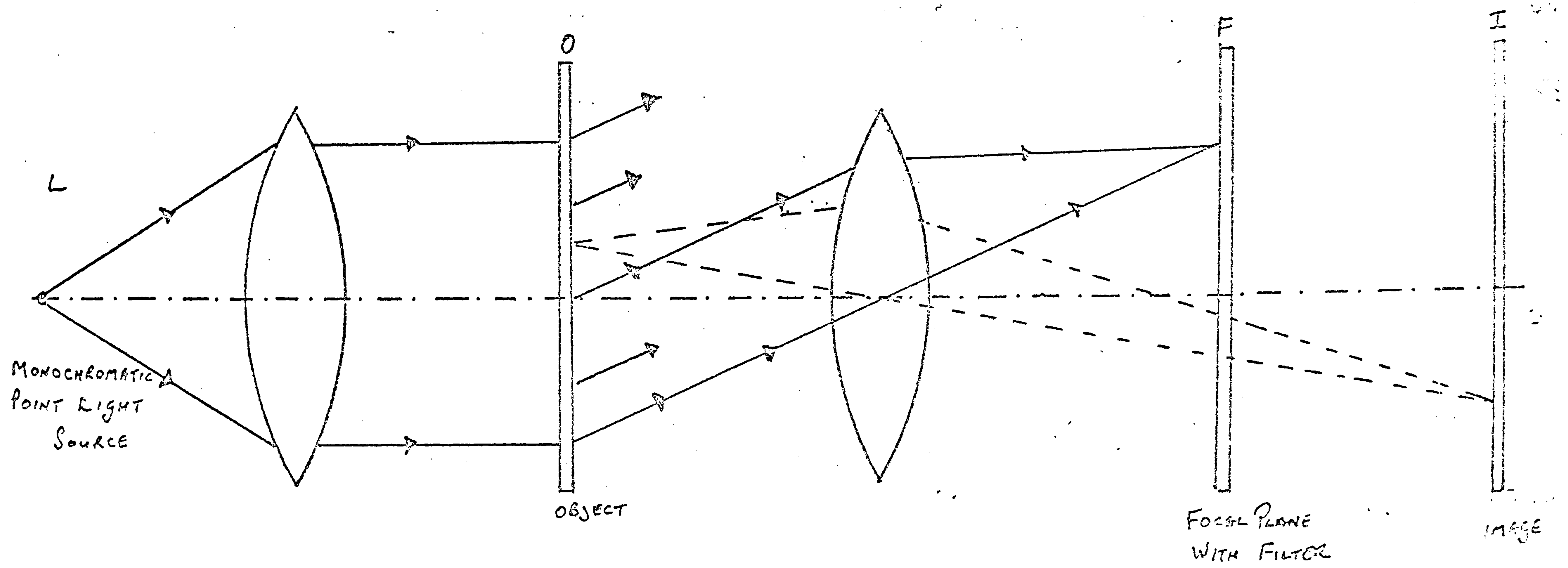

Fig. 5.1. Optical Arrangement With a Slide S in O and a Hologram H in F [After Van Heerden, 1968]

by producing P_o as a virtual image of the original light source, by a system of half-silvered mirrors. After the hologram was made of $S + P_o$, S_1 could be put back in the object plane, and the ghost image contained one bright image of P_o which was readily recognized. The displacement of P_o from the centre indicated the displacement of S_1. When it was required to regenerate information in S adjacent to S_1, as would be the case for prediction (or any other use of the memory), S_1 had only to be moved until the ghost image of P_o coincided with its original position. If P_o, now, was turned back on a bright, relatively noise-free ghost image of the whole slide, S, with S_1 in its proper context, would appear in the image plane. (An alternative method would be to generate a light spot in O corresponding to the position of the displaced ghost image of P_o in I.) (VAN HEERDEN, 1968).

A design for a practical realization of such a system is shown in Figure 5.2. In the object plane O a transparency, S, was presented which contained in parallel strips, the time series of all the inputs —the different drives such as hunger and pain, and the different sense impressions, as from the eye and ear, from the beginning up to the present time. There was also an output plane with a transparency T, which had stored all the time series of all the commands to the muscles. By means of a semi-transparent mirror, S and T were superimposed to give an image of (S + T) together with the point source P_o in the centre of O. A television camera tube could be placed at I, the output of which, if connected to

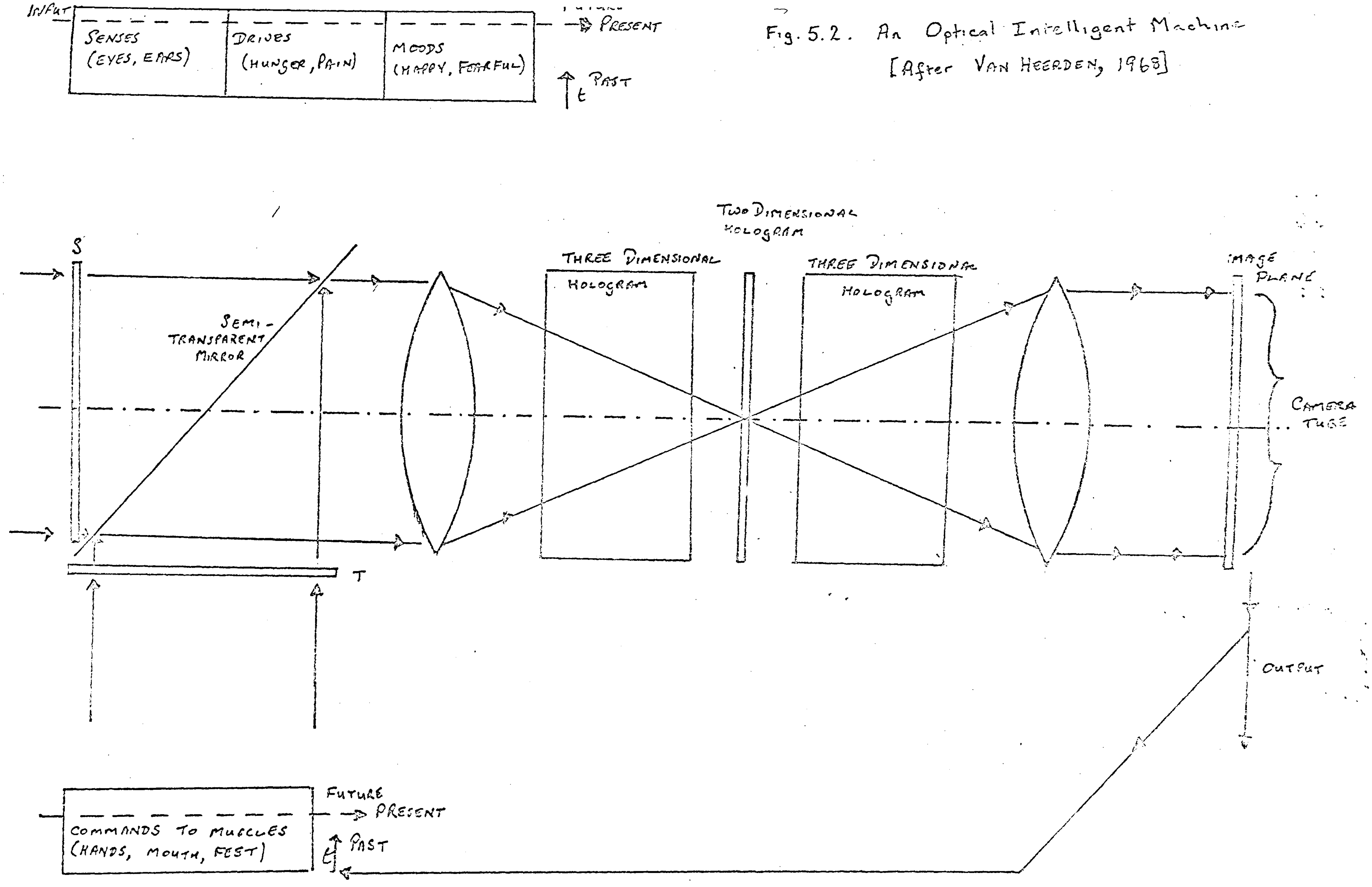

Fig. 5.2. An Optical Intelligent Machine [After Van Heerden, 1968]

the necessary electronics, could find the brightest spot in I, then, by the use of a servo mechanism move (S + T) to the position where the brightest spot coincides with the origin and turn on P_o, the point source. If the hologram was illuminated by the light from the immediate past of (S + T) only, for instance by screening off the rest by an opaque screen, selecting the brightest ghost image of P_o and moving it to the origin, the turning on of P_o provided a rational prediction of S + T in the image plane. This manner of prediction was a natural extension of the system $(1 + D^k)$ for one time series, since there were many independent time series in parallel. The machine, therefore, looked for the best match, in the past, of the overall pattern. The aim of the machine was to make S equal to zero, or as close to zero as possible and, therefore, the output T was chosen so that it was equal to (S + T), T = S + T, and S = 0. The output in the image plane, I, would now form the command to the muscles. It could be taken out, for instance, by the same camera used for the search. It also had to be recorded, permanently, in the transparency, T. This mathematical instruction to the machine corresponded to the commonsense advice: "If it worked in the past, do it again; if it did not, try something else" (VAN HEERDEN, 1968).

What makes the use of the hologram so "life-like" in its capacity for search was the possibility, by very simple means, of trading speed for recognizability, and then again increasing recognizability for objects, or actions which were appropriate to the situation. In the first place, one picture element of the camera tube could be made to cover, say, 100 picture elements of the image plane. Now the signal to noise ratio had decreased by a factor of $\sqrt{100} = 10$, and the situation now required a higher level of recognizability (VAN HEERDEN, 1968).

In the second place, the signal to noise ratio could be increased again in specific situations. This could be achieved by, say, coating the hologram with a thin layer, which was uniform and only 1% to 10% transparent, but, which when bleached by illumination with light the transparency rose to 50% to 100%. If initially there was a drive such as hunger, then its Fourier spectrum in the hologram plane would bleach the layer in specific spots. The hologram would be, now, more transparent for those sense impressions and muscular outputs which were connected with this drive, since their spectrum would be present at the same place in the hologram. The signal to noise ratio was now increased in particular for those activities related to the satisfaction of the drive of hunger, thus making a faster search possible. The system acts as if hunger increased the recognizability of food! (VAN HEERDEN, 1968).

A further modification can be made. The object plane at the present moment displays the whole life story. Van Heerden (1968) proposed that at any instant, one one small instalment was displayed, after which the spectrum was stored in the hologram, and the object plane was erased to make room for the second instalment, and so on. It now became necessary to use, besides the point source, P_0, which was used for all instalments, a second redundant pattern which was different for each instalment. These second patterns could be, for instance, point sources P_1, P_2 ..... P_n etc., which were positioned in different places of the object plane. The procedure in the automaton, to decide on its action in a particular situation, now consisted of two parts. First it sought out the ghost image of P_o, which was the brightest spot in the image plane and brought it to the centre. Then it carried out a second search, for the brightest point among the possible P_1, P_2, ... P_n. If it turned out to be P_k, then the source P_k was lit up, which resulted in the proper prediction and the plan of action.

This proposed modification was equivalent to the original machine, except that the hologram contained n unrelated holograms superimposed, leading to a decrease in recognizability, or a decrease of the signal to noise ratio by a factor of $\sqrt{n}$. However, this was compensated by a permanent increase in speed of a factor n. The decreased recognizability could be partly increased, as pointed out above, by the drive which was active, the activity the machine was engaged in, or even, in anthromorphic terms, the mood the machine was in. There existed, however, an additional technical improvement which made almost complete recall, as in the first model, possible. This improvement was to add to the flat, two-dimensional hologram a three-dimensional hologram (VAN HEERDEN, 1968). This was not useful in the initial search for P_o, since a three-dimensional hologram gave no ghost image for displayed P_o. However, once P_o had been chosen and centred, the choice of P_k, and the information yielded by turning on P_k was much freer from noise (VAN HEERDEN, 1968).

The technological problems of building optical intelligent automata are very specific. The development of electronics has provided microphones and television systems of high perfection. They can transform sound and visual scenes into electrical signals. These signals can be made into transparencies by the skotophor (LEVERENZ, 1950) or the eidophor (GRETENER, 1958; GLENN, 1958) principles. In the skotophor, a scanning electron beam wrote, in a vacuum, on a thin layer of potassium chloride or other material that was coloured by the bombardment of the high-voltage beam. In the eidophor tube, an electron deposited a charge on a thin oil layer, which then would display a curvature of its surface wherever a line or point of charge was deposited. Therefore, the light changed its phase differently at each different point of the image written (VAN HEERDEN, 1968).

For a permanent memory in the form of a transparent two-dimensional or three-dimensional hologram, the present photographic techniques are less suitable. Better suited will be semi-transparent coloured materials which can be bleached in place. The main requirement is that they are permanent, and yet that new information can be added in the course of time. One can imagine materials which are relatively insensitive to bleaching, so they can be read out by weak light again and again with very little deterioration, and new information could be added with the aid of a very powerful laser light source. There will also be needed optical systems specially built to be free of aberrations for monochromatic light only. According to Van Heerden (1968) all these things seem to be well within the range of existing technology.

Chapter 6

THE APPLICATION OF HOLOGRAPHIC TECHNIQUES TO PREDICTION

6.1. Introduction

The use of computers in problems concerned with pattern recognition and image processing has, because of the obvious promise, invited a large amount of research in recent years. Despite all this endeavour, however, the results have so far been disappointing. If significant progress were to be made in this field it would lead to the possibility of optical guided robots, reading machines, automatic optical inspection systems and similar devices. Approaches involving programming a computer to carry out this task run into the difficulty of formulating the problem in a precise enough manner, whereas using the computer to investigate every point of the pattern requires a large processing time and an enormous memory store.

One solution that has been proposed is the use of holograms. For example, Gabor (1965) proposed the recording of a hologram consisting of the Fourier transform of the character to be recognized, along with the Fourier transform of an array of point sources. If this hologram was illuminated by light which had first passed through a transparency of an unknown character, and these two characters were the same, the array of point sources would appear in the output plane of the final lens in the system. It has been pointed out (ULLMANN, 1973), however, that the two patterns were seldom precisely identical, and that the photographic and optical systems departed from their ideals, and as a result it did not appear to be a useful technique for character recognition (DICKINSON and WATRASIEWICZ, 1968).

The holographic methods so far discussed are essentially non-weighted mask matching (see ULLMANN, 1973). This is not a basic limitation of holography. It is possible to generate holograms by a digital computer (ANDREWS, 1970; LOHMAN and PARIS, 1969), and thus it is possible to compute a weighting function. This hologram can be then used instead of the optically produced hologram in Gabor's recognition system. Such a system would have the possibility of frequency filtering, and the avoidance of noise arising from optical/electrical transduction and spatial sampling on a finite grid. In practice, computer generated holograms do not appear to be used in character recognition, and perhaps one reason for this is the overriding disadvantage that light reflected from paper is unsatisfactory for holographic purposes (ULLMANN, 1973).

In this chapter we are going to investigate a method of predicting the future values of a simple time series. As has been argued above, the main disadvantage of using holographic techniques is that the function being studied has to be converted into some form that can be illuminated by coherent radiation. Ordinary paper, for example, has the disadvantage that, compared to the wavelength of light, its surface is very rough and so introduces a large amount of noise into the system. If it were possible to produce a "real-time" transparency it is possible to conceive of a system based on a hologram that would act as a predicting filter in that, given the first part of a time series, the filter would produce a later section of the same time series. It is possible to use a hologram to perform autocorrelation or cross correlation. A large number of possible time series can be kept on a hologram, the degree of cross correlation between the unknown time series and those on the hologram is indicated by a bright spot, the brighter the spot the greater the degree of correlation. This means that the criterion is the opposite to Gabor's in that the system is looking for a maximum not a minimum. The ideal of such a system would be one that could learn in the same way as Gabor's, by using a training set; the filter attempts to predict the future states of members of this set. Having made such a prediction it can then compare its prediction with the actual value and accordingly alter its weightings.

6.1.1. Spatial Heterodyning

If a real-time transparency is available, a process that could be called "spatial heterodyning" is worth considering (CATHEY, 1974). Spatial heterodyning is a process of multiplying the spectra of two signals directly and then transforming the product, rather than recording a filter using one signal and then illuminating the filter with the spectrum of the other signal (RAU, 1966a, 1966b; WEAVER and GOODMAN, 1966). Fig. 6.1 shows a mechanism using a transparency having transmittance at a wavelength λ_1, which can be modulated by illumination with energy at a wavelength λ_2. The source S_1 emitting λ_1 illuminates transparencies of the functions $g(x,y)$ and $h(x,y)$. The transform distributions illuminate the transform plane transparency with energy at wavelength λ_1

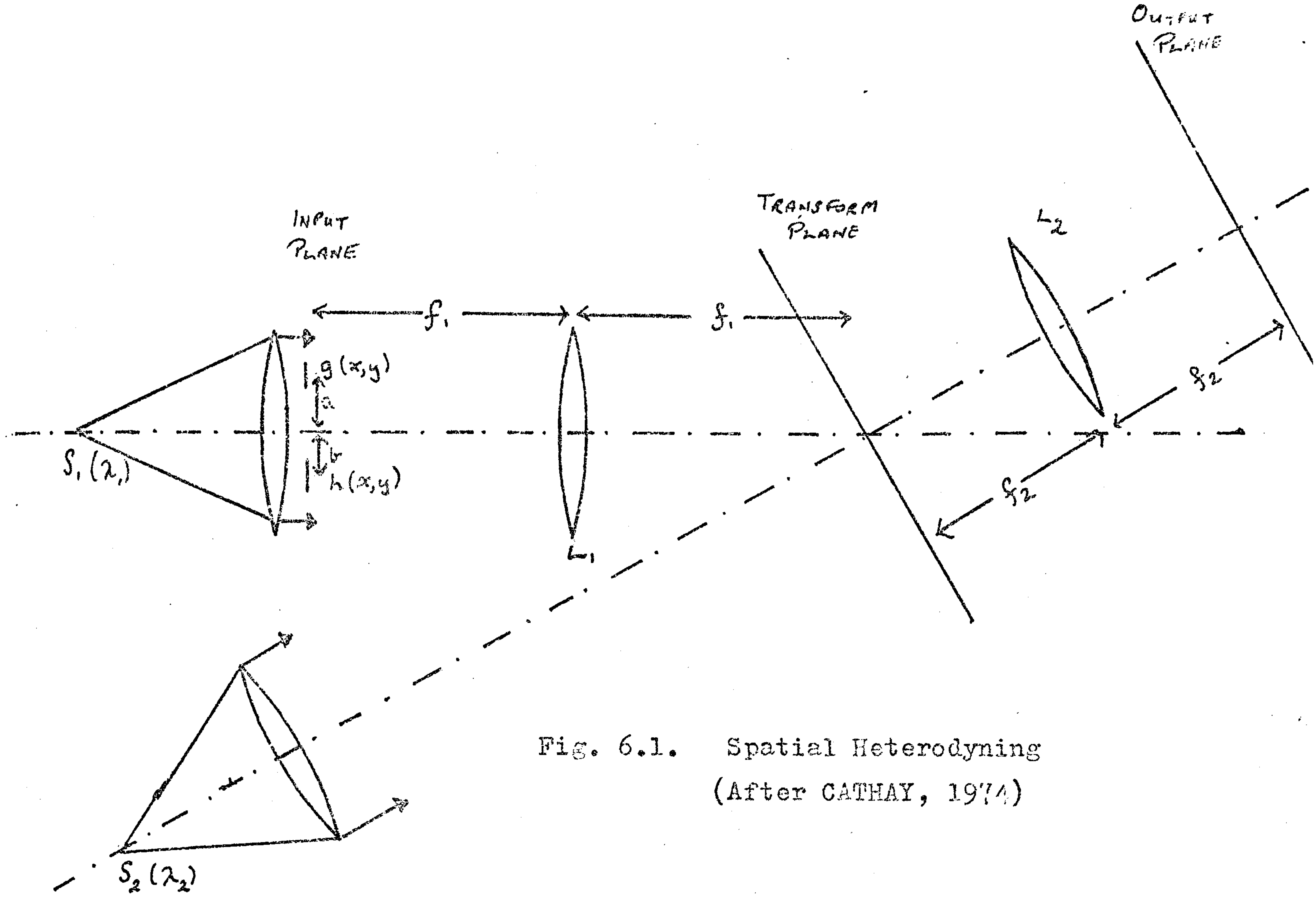

Fig. 6.1. Spatial Heterodyning
(After CATHAY, 1974)

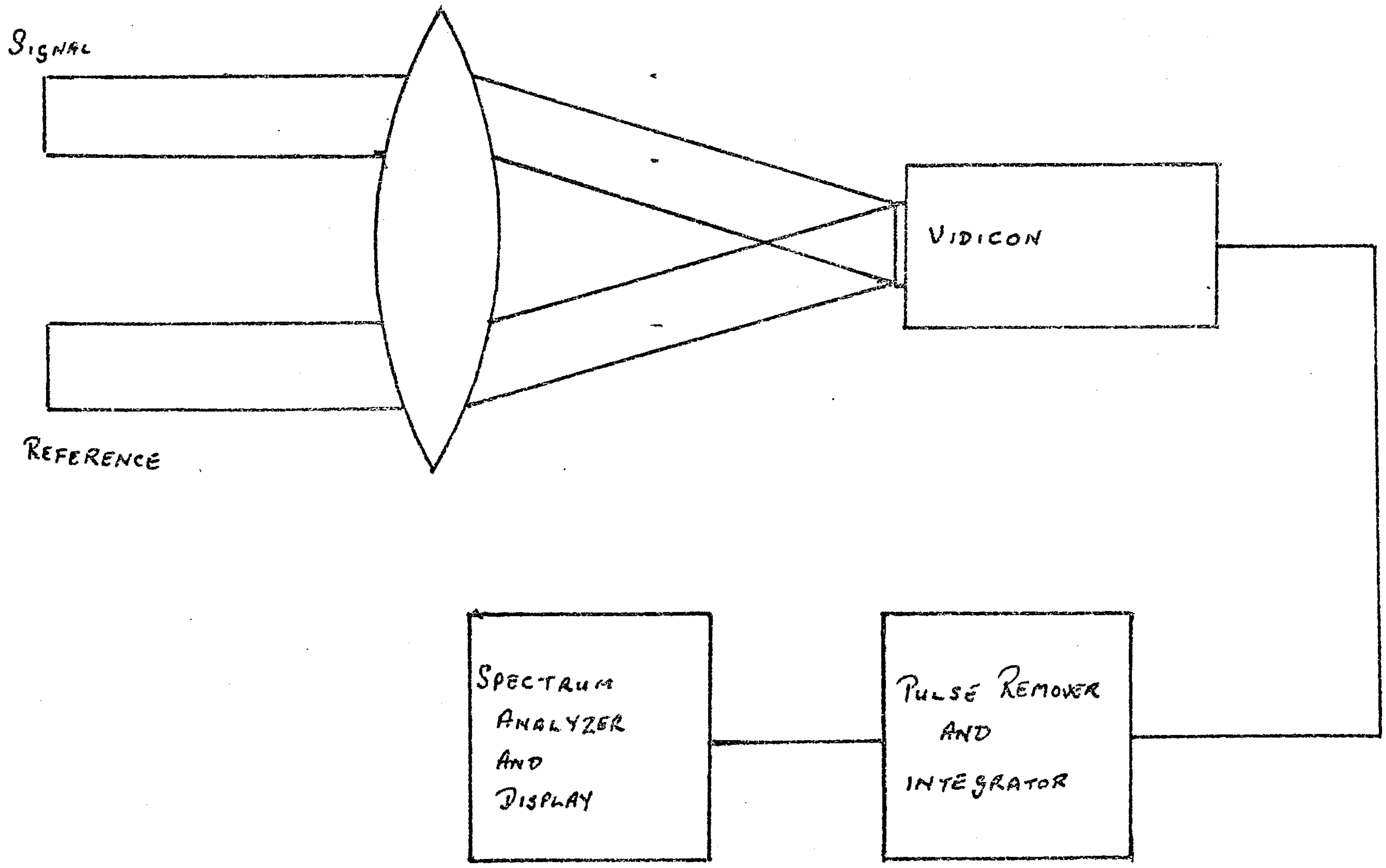

Fig. 6.2. A Hybrid Optical-electronic Spatial Heterodyning System
(After CATHAY, 1974)

causing its transmittance at λ_2 to vary. The resulting wave with wavelength λ_2 is Fourier-transformed by the lens L_1 and, as can be shown (CATHEY, 1974), a correlation of g(x,y) with h(x,y) is obtained in the output plane. This correlation of g and h appears off-axis by an amount equal to $(\pm \lambda_2 f_2/\lambda_1 f_1)(a+b)$ and the autocorrelations appear on-axis. With this technique no convolutions appear.

6.1.2. Hybrid Optical-electronic Systems

There are a number of hybrid systems that attempt to use the better characteristics of both optical and electronic systems. Most of these employ a scanning optical sensor to feed data into a computer which performs the correlation. These systems, while effective, are slow and require a considerable amount of computer capability (CATHEY, 1974).

One system uses the spatial heterodyning approach (RAU, 1967) and is shown in Fig. 6.2. The inputs were illuminated by a uniform plane wave. The lens L produced the transform in the plane of the vidicon. The vidicon converted the spatial signal into a temporal signal, associated electronics removed the sync and blanking pulses and integrated the signal over one vidicon frametime. The spectrum analyser then transformed the signal from the time domain to the frequency domain, an operation analogous to the operation of the last lens of Fig. 6.1.

The vidicon scanned the fringes produced by the interference between the spatial signal and reference, and produced a signal frequency dependent upon the scan rate and the fringe spacing. The spectrum analyzer isolated this signal.

Because the fringe spacing was dependent on the separation of the reference signal and the input signal, the frequency displayed on the analyzer was indicative of the horizontal distance between the input signal and the reference signal. The strength of the signal was dependent on the visibility of the fringes and the area over which the fringes appeared. Consequently, interference patterns between like spectra produced a stronger signal than interference patterns between unlike spectra (CATHEY, 1974).

6.2. Spatial Light Modulators

The input of a holographic recognition system is usually a photographic transparency. There are a number of disadvantages in using transparencies including the time needed to develop the film, the irreversibility of this developing process, and the noise introduced by the "graininess" of a photographic film. Several systems have been suggested to produce inputs that can be used immediately and repeatedly, so called "real time" transparencies or spatial light modulators (see CATHEY, 1974; PRESTON, 1972). There is another disadvantage in using a transparency to predict future states of a time series. Time series often consist of data being transmitted electronically at given time intervals, so that this electronic signal has to be converted into some form of optical signal.

Below are described some media which could form spatial light modulators. They fall into two basic types, those that alter their transparency to light and thus modulate the wavefront amplitude and those that alter the phase between points in the wavefront and are referred to as phase modulators. A photographic plate is an amplitude modulator.

6.2.1. Acoustical Holograms

Some experiments have been carried out on acoustical holograms with frequencies just above audio (METHERELL, 1969a), but most of the practical work has been at ultrasonic frequencies of 1MHz to 10MHz; this covers the frequencies most used in medical diagnostics and non-destructive testing. The wavelengths involved are 1.5mm to 0.15mm in water, increasing by a factor between 2.5 and 4 for dilation waves in metals. Both pulsed and continuous ultrasound have been used with water as the medium carrying the sound to the object under view. With continuous ultrasound, it has been found necessary to line the sides and the bottom of the tank with sound-absorbent material; this damps out the standing waves which otherwise form in the water and give rise to poor acoustic images (HOLT and COLDRICK, 1969).

The optical reproduction requires light of a coherence dependent upon the size of the hologram; generally, the coherence of the laser is not necessary. In practice, however, a laser is always used, as the amount of light diffracted by the hologram into the desired image is small, and the intensity of the light from a laser makes for convenient viewing. Usually, the image is viewed by means of a television monitor used in conjunction with the laser, this permits the system to be used in normal light with advantage to the operator. The laser is usually the continuous-wave helium-neon type producing a red light with a wavelength of 0.633 microns (ALDRIDGE, 1971).

The propagation of sound is basically a non-linear phenomenon, and it is only when the amplitudes of vibration are small that it can be considered as a linear wave motion. This means that an acoustical hologram can be formed in a way analogous to an optical hologram.

A travelling acoustic wave in a liquid transports liquid, and if an acoustic beam is directed upwards at the surface of the liquid it will produce a permanent displacement of the surface, across the beam wavefront; this is usually several orders of magnitude greater than the amplitude of the surface vibrations. A scheme which utilises this effect is illustrated in Fig. 6.3 (ALDRIDGE, 1971).

Two transducers driven from the same generator are placed in a water tank and oriented so that their beams overlap at the water surface. In addition to the surface displacement the interference of the beams produces a static ripple pattern. When an object is placed in the path of one of the beams, the other beam serving as the reference, this ripple pattern is modified by the sound scattered by the object. The resultant static surface displacement is then the acoustical hologram. This is used as an optical phase hologram and the acoustical images are viewed by means of coherent light reflected from it.
In the absence of the sound the water surface is a flat plane, and the light reflected from it is focussed to a single spot. With the sound present, but without the object, the resulting surface ripple causes the central spot to be

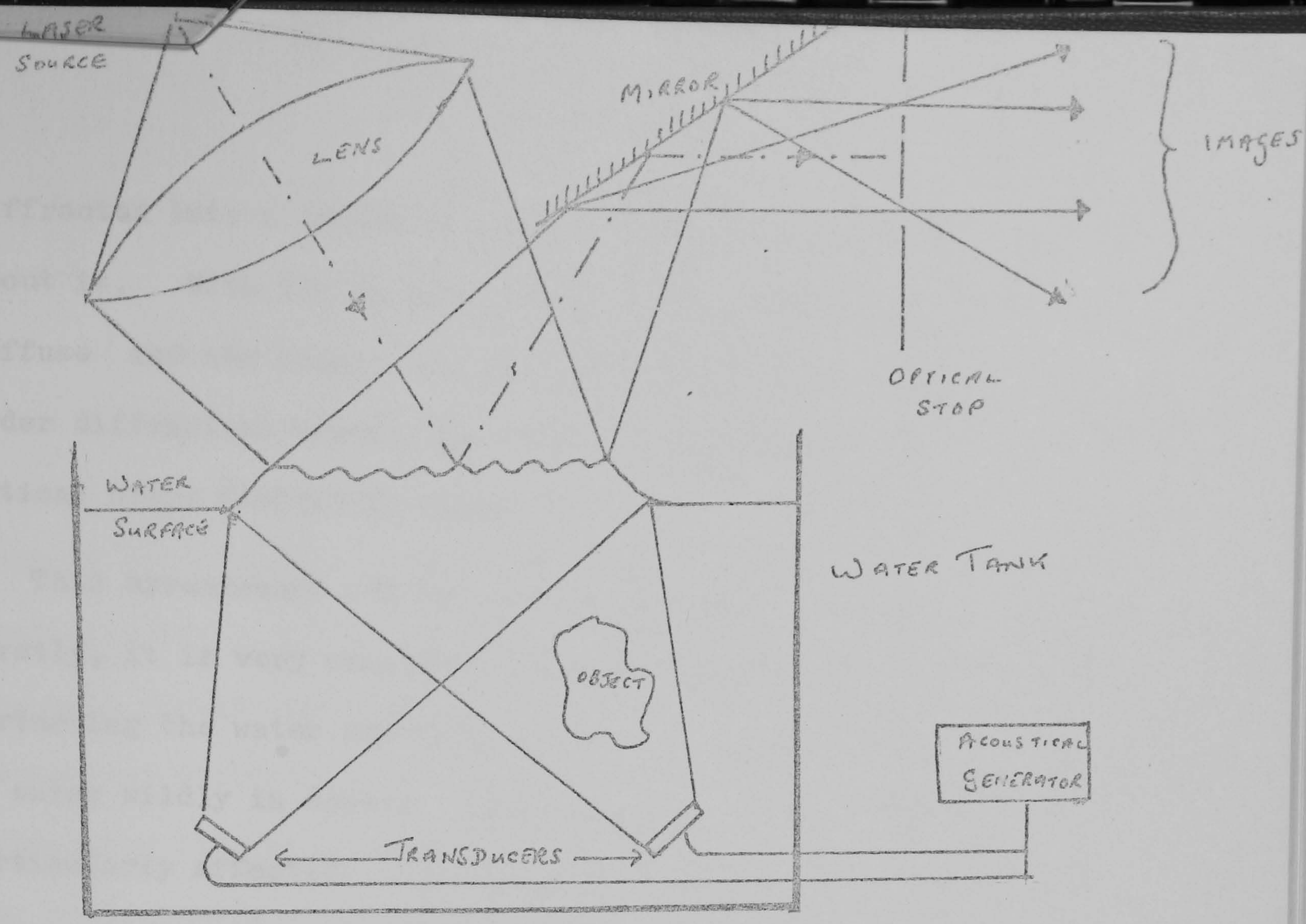

Fig. 6.3. Holographic System using Water Surface Levitation
(After ALDRIDGE, 1971)

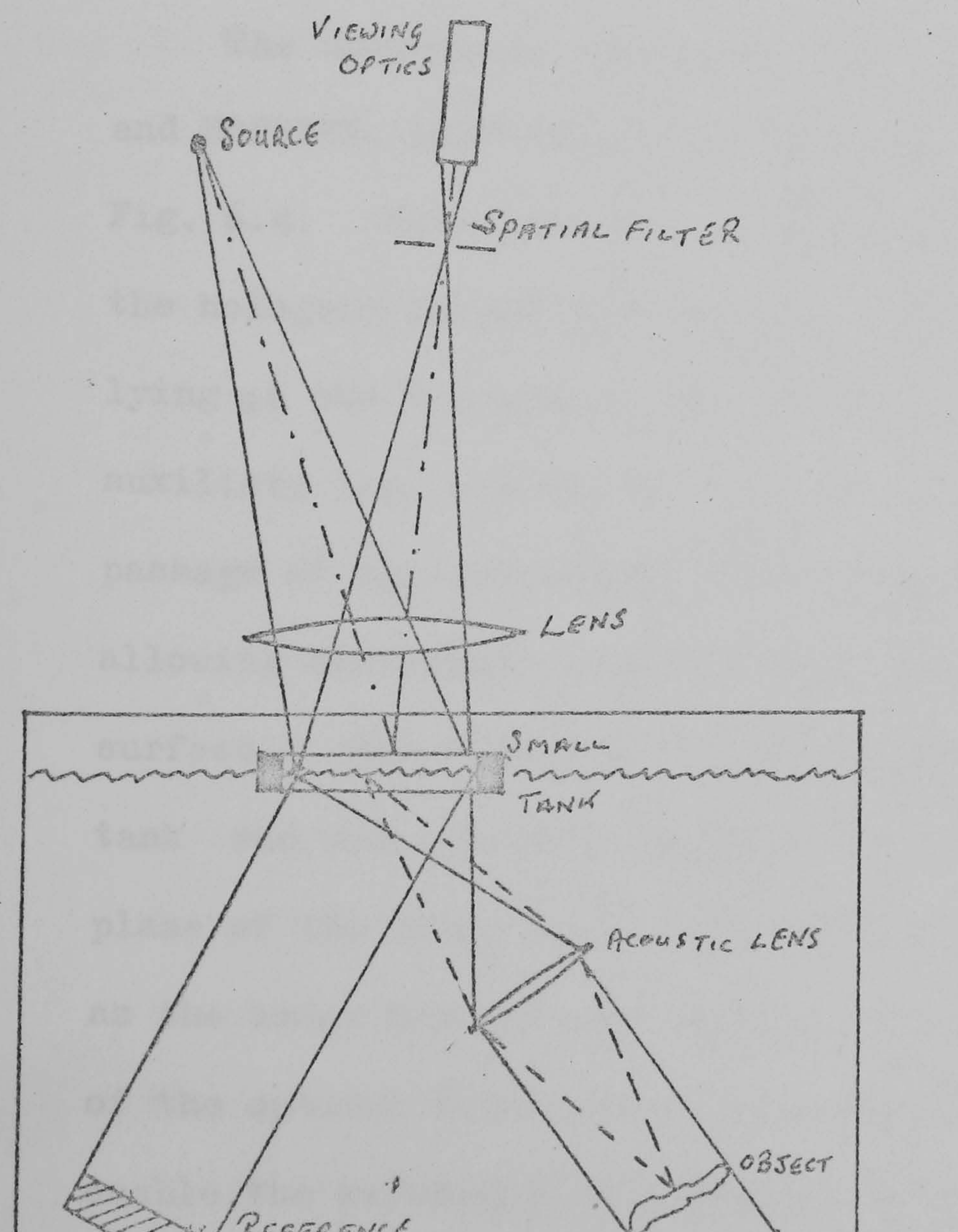

Fig. 6.4. Commercial Holographic System (After ALDRIDGE, 1971)

diffracted into a number of others lying symmetrically about it. With the object present these spots become diffuse and the images can be seen by viewing the first order diffraction spots, the others being removed by optical stops (ALDRIDGE, 1971).

This arrangement has two serious disadvantages. Firstly, it is very sensitive to vibration which, in perturbing the water surface, causes the optical images to swing wildly in space; the hologram as such is not particularly affected. Secondly, the hologram is the same size as the acoustical aperture which, if it is to be useful, is large in terms of light wavelengths. Because of its size, this places rather stringent coherence requirements on the optical illumination (ALDRIDGE, 1971).

The commercial version of this system (HOLOTRON CORPORATION; and BRENDEN, 1967 and 1969) is shown diagramatically in Fig. 6.4. Here the first problem has been solved by forming the hologram on the surface of a shallow auxiliary tank lying on the surface of the main tank. The bottom of this auxiliary tank was transparent to sound; it permitted the passage of the acoustical wavefronts without, however, allowing disturbances in the main tank to affect the hologram surface. The object to be viewed was placed in the main tank and was imaged by means of an acoustic lens onto the plane of the hologram. This ameliorates the second problem; as the image has already been formed the coherence required of the optical illumination need be sufficient only to enable the reference beam grating to diffract the light.

The image was obtained by looking along the appropriate diffracted beam and focussing the optical system on to the plane of the hologram. The sound intensities required were about 0.1w/cm^2 (WORLTON, 1968), although the threshold sensitivity is about a hundred times less than this (BERGER and DICKENS, 1963). The ultrasonic frequencies available are 3, 5, 7 and 9MHz. According to Worlton (1968) the best results have been obtained by pulsing the transducers for approximately 80 microseconds duration at a pulse repetition rate of about 300 per second, and the technique has successfully extended to ultrasonic frequencies of 50 MHz.

6.2.2. A Liquid Crystal A.C. Light Valve

One way round the problem of preparing transparencies is to make use of the technology of liquid crystals. Hughes Research Laboratories have designed a device known as a photo activated A.C. liquid crystal light valve which has been incorporated into a holographic pattern recognition system (GARA, 1977). A diagram of the device is shown in Fig. 6.5. It consisted of a series of layers. The first layer was a glass window on one side of which was deposited an antireflection coating and on the other side came a transparent electrode. Sandwiched between the electrode and a dielectric mirror was a nematic liquid crystal. After the dielectric mirror came a light blocking layer followed by a layer of material that changes its conductivity with incident light. Then came another transparent electrode; the two electrodes being connected through an electrical oscillator, with an output of between 3.5 and 5 volts at a frequency of

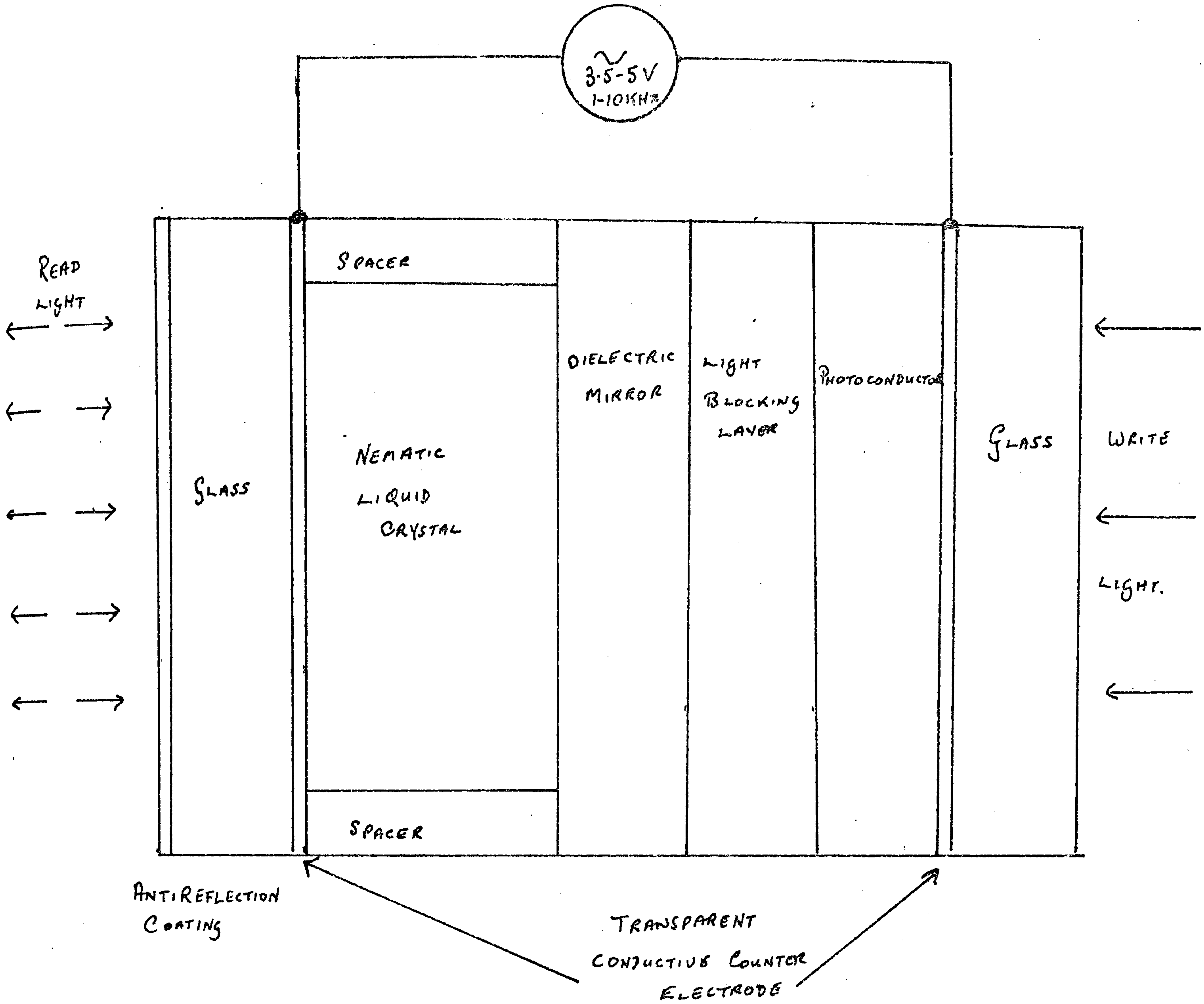

Fig. 6.5. Photoactivated A.C. Liquid Crystal Light Valve
(After GARA, 1977)

between 1 and 10 kHz. Another sheet of glass completed the device.

This device makes use of the ability of this type of liquid crystal to rotate the plane of polarization of a light beam, the amount of rotation depending on the voltage across the liquid crystal. The voltage across the liquid crystal was controlled by the conductivity of the photo conducting material which could be altered by light falling on it. This light might have been coherent or incoherent and could be from any suitably illuminated object - this was known as the writing light. Through the liquid crystal was shone a linearly polarized coherent beam of light which was then reflected by the dielectric mirror - this was known as the read light. In the off state (no writing light) the read light emerged from the liquid crystal with its polarization state unchanged. As the intensity of the writing light increased the voltage across the liquid crystal increased, causing the plane of polarization to rotate, or, to put it another way, the read light acquired a component of polarization at right angles to the original plane of polarization, the amplitude of which was proportional to the intensity of the writing light. The read light was then passed through a suitable polarizing filter and a new polarized beam emerged with a plane of polarization at right angles to the original beam. This coherent beam had an intensity proportional to the incoherent light from the object under study.

6.2.3. Photochromatic Materials

The term photochromatic is usually applied to reversible spatial light amplitude modulating materials. Photochromatic materials can be switched reversibly between two states, one of which, at least, is characterized by the absorption of visible light. (The more general term Phototropism refers to materials having two or more states which can be detected by the absorption of some form of electromagnetic energy, but not necessarily in the visible wavelength region.) Typically, photochromatics, when in their equilibrium or "bleached" state and illuminated with radiation in the ultra violet and/or in the short length visible region of the electromagnetic spectrum, undergo chemical changes which generate absorption bands in the medium- to long-wave length region of the visible spectrum. Illumination by those longer wavelengths (and/or thermal decay) causes the photochromatic material to revert to its bleached state. Brown and Shaw (1961) and Exelby and Grinter (1965) have published general surveys of photochromatic materials. These materials can be used in the form of films or used in the manufacture of special types of glasses.

The advantage using these materials for spatial modulation of light is that they have great resolution at the optical wavelength (PRESTON, 1972). This is because the light modulating effect occurs at the molecular level. Conversely, this means that large energies are required for signal recording and bleaching of the order of $10^{20} - 10^{22}$ photons/cm^2 ($\sim 10 - 100$ J/cm^2) (KNAPP, 1965). This, of course, is not necessarily a disadvantage as far as the laying down of permanent memories is concerned.

6.2.4. Thermoplastic Films

Thermoplastic film consists of a substrate (frequently Mylar) coated with a thin transparent conducting layer which is in turn overlaid with a thin film of a plastic with a low melting point, which softens, typically between about 60 - 100° C. Initially, during the erasure cycle, the thermoplastic layer is heated above its softening temperature. The effect of the surface tension is to pull the surface flat. Also, since the thermoplastic is relatively electrically conductive when heated, any residual electric charge is removed and the entire film is discharged to the potential of the transparent conductive under layer.

After cooling to room temperature a record is made on the thermoplastic layer by means of a scanning electron beam (usually in vacuum). Alternatively, when the thermoplastic is made in a photoconductive form, the film is first flooded with electrons which are then selectively removed by exposure to light. The signal charge pattern recorded remains in place because of the high resistivity of the thermoplastic film when at room temperature. Next a second heating cycle is performed, and the softened thermoplastic is now under electrostatic pressure due to the recorded surface charge pattern and so deforms in accordance with the recorded pattern. Such a recording is an optical spatial phase modulator. This process is an adaptation of the Xerographic principle (URBACH and MEIER, 1966).

6.2.5. Deflectable Membrane Mirrors

The membrane light modulator was initially described by Preston (1968) and was an optical phase modulator which phase modulates light reflected from its surface. Phase modulation was accomplished by electrostatic surface deformation of discrete phase-modulating surface elements. Two types of membrane light modulators have been described:

1) The wired membrane light modulator in which surface deformations were produced by means of signals applied to stripe electrodes underlying the mirror surface.

2) The photosensitive-membrane light modulator in which surface deformations occurred on the mirror side of the device in response to the local light intensity level present on the opposite side of the device.

The device was formed by depositing stripe electrodes on an optically flat glass substrate over which a thin layer was deposited. Microscopic perforations were formed in the dielectric layer using standard photolithographic techniques. The perforation diameter was between 5 and 10 μm with a depth of the order 1 μm. Overlying the perforated layer was the membrane mirror. It is usually made of a polymer, such as colladion, 0.1 μm thick and metalized to enhance reflectivity. The metalized surface had also to be sufficiently conductive so that it could be held at a fixed electric potential.

Voltages impressed on the stripe electrodes produced an electrostatic attraction between the membrane metalization and the electrode, causing all unsupported regions of the membrane mirror in the field to deform. For circular perforations the deformation was paraboloidal. Signal voltages of the order of a few tens of volts were sufficient to produce a half-wavelength deformation at the centre of each paraboloid, thus causing a full 360^o phase reversal of the reflected light at this point.

The wired membrane light mirrors, when used as the input transducer in a holographic recognition system, was capable of handling only one dimensional signals. This was because the phase modulation was identical along the entire length of each stripe electrode and varied only from electrode to electrode. A membrane light modulator which was a two dimensional optical spatial phase modulator, the photosensitive-membrane light modulator, has been reported by Reizman (1969). This was constructed from a semi-conductor crystal, such as a n-type silicon, sliced and polished to a thickness of 50 to 100 μm. An array of p-n junction diodes was diffused into the mirror side of the device, with one diode for each membrane element. Next, a perforated layer of a highly resistive material, such as a semi-insulating glass, was deposited. The resistivity of this layer was chosen to be intermediate between the effective dark resistivity of the p-n junction diodes and their effective resistivity when fully illuminated. A perforated collecting electrode was next deposited so as to make an ohmic contact with the resistive layer. The metalized polymer membrane was then applied over the entire structure. Finally, the side of the photosensitive-membrane light modulator opposite to the membrane mirror surface was heavily doped in a shallow diffusion. This diffusion formed an electrode which was transparent in the long-wavelength region of the visible and in the near infra red.

To use the photosensitive membrane light modulator, a potential of a few tens of volts was applied between the collecting electrode and the transparent electrode, of a polarity such as to back-bias all members of the p-n junction diode array. The metalization on the membrane mirror was usually held at the same potential as the collecting electrode. When the input side of the photosensitive membrane light modulator, i.e. the side opposite the mirror surface, was not illuminated most of the applied voltage appeared across the p-n junctions. Thus, there was little or no potential to deflect the elements of the membrane mirror and essentially no surface deformation occured. When light was allowed to impinge at a point on the input side of the photo sensitive membrane light modulator, hole electron pairs were created. Holes diffused towards the p- regions were collected by the nearest p-n junction, and were swept through its depletion layer. The current so created flowed through the associated portion of the resistive layer and produced a potential difference between the p-region of the p-n junction diode and the metalization on the membrane, causing the associated membrane element to deflect.

Other types of spatial light modulators using a deformable surface are being developed along the lines of the Eidophor (MOL, 1968; BAUMANN, 1953) where an oil film was deformed by means of a charge deposited by an electron beam. There has been, for example, the development of cathode-ray tubes having deformable face plates. A typical example is where a face plate was constructed of a matrix of wire pins hermetically embedded in glass (HAMANN, 1966). Over the surface of the face plate was a fluid film which was deformed electrostatically, much as with the oil film in the Eidophor. In this way a spatial phase modulator operating in reflection was created.

6.2.6. Elasto Optic Delay Lines

The optical spatial phase modulator which has been used most frequently as an input transducer is the transparent acoustic-delay-line light modulator (PRESTON, 1972). In this device the input signal appeared in the form of a travelling acoustic wave in either a liquid or solid medium. By illuminating the delay-line medium appropriately, spatial phase modulation of the incident light wave was produced. This interaction between light and sound was due to the elasto optic coupling which exists between strains produced in the medium by the sound wave and the dielectric constants of the medium. Alternatively, this effect could be regarded from the quantum mechanical point of view as a phonon-photon interaction.

The interaction of light and sound has been extensively investigated. Historically it was first predicted by Brillouin (1922). In the early thirties Debye and Sears (1932) as well as Lucas and Biquard (1942) made initial experimental demonstrations. Later in the 1930's, applications of the effect to television signal processing, of which Okoliesanyi's (1939) is typical, were devised. More recently Rosenthal (1963) described an application to radar signal processing. Since that time the effect has been extensively exploited by Lambert (1960), Preston (1969), Slobodin and Reich (1965) and others. This subject has been treated rigorously by Gill (1964).

Besides phase-modulating light in transmission by means of travelling bulk acoustic waves, it is possible to spatially modulate light by means of surface waves (PRESTON, 1972). In these devices, since light incident on the surface is modulated in reflection, phase modulation of a few tenths of a radian could be produced for surface motions of only a few tens of angstroms. Unlike bulk acoustic waves, a low acoustic velocity was preferred because it permitted an increased space-bandwidth product. Surface waves are also of interest because they may be guided in a zig-zag fashion which contributes to an effective match between such a light modulator and the two-dimensional aperture of the associated holographic system. (See KROKSTAD and SVAASAND, 1967; IPPON, 1967; LEAN and POWELL, 1970.)

6.2.7. Comparison of Spatial Light Modulators

Other methods for producing "real-time" transparencies include altering the transmission of a colloidal solution (KAZAN et al, 1968) and the electrolytic deposition of an opaque salt on the transparent walls of an electrolytic cell (ZARCOMB, 1966 and HOFFMAN, 1966).

Table 6.1 compares the different types of spatial light modulators and is taken from Preston (1972).

6.3. A Predicting Filter

It has already been stated that a general solution to the problem of predicting the future values of a given time series would be of great practical value (see, for example,

	Silver Halide (Photographic Film)	Photochromic	Thermoplastic	Deformable Membrane	Elasto Optic
Maximum Linear Storage Density, cycles/mm	10^3	$> 10^3$	3.10^2	10^2	50 (isotropic); 2.10^3 (crystal)
Energy Required, J/cm^2	$10^{-8} - 10^{-6}$	$10^{-2} - 10^{-1}$	10^{-9}	10^{-4}	$10^{-7} - 10^{-5}$ (J/cm^3)
Minimum Record Time, S	$< 10^{-9}$	$< 10^{-9}$	10^{-8}	10^{-8}	10^{-8} (isotropic); 10^{-10} (crystal)
Development Time, S	1.0 — 10.0	Not Applicable	1.0 – 10.0	Not Applicable	Not Applicable
Decay Time, S	∞	$10^{-3} - 10^{7}$	∞	Not Applicable	Not Applicable
Minimum Erasure Time, S	Not Applicable	10	$10 - 10^2$	Not Applicable	Not Applicable
Life	Indefinite	Finite Number of Cycles	Finite Number of Cycles	$> 10^{12}$	Indefinite
Maximum Linear Space - Bandwidth Product	10^5	$> 10^5$	$\approx 10^3$	$\approx 10^3$	10^3
Maximum Area Space-Bandwidth Product	10^{10}	$> 10^{10}$	$\approx 10^6$	$\approx 10^6$	10^4

Table 6.1. Comparison Of Spatial Modulators

[After Preston, 1972]

GABOR, WILBY and WOODCOCK, 1960), but such a solution has proved to be elusive. The same is true of a general pattern recognition machine and it has been the purpose of this thesis to show that a machine capable of predicting the future values of a time series would also be capable of pattern recognition. This is because, in order for a machine to be able to predict the future states of a time series, it must be able to recognize the historic features of the time series under consideration. In order to bring this thesis to a conclusion we shall consider a simple time series which is sufficiently complex to be of interest but not so complex that it is totally unpredictable.

6.3.1. The Problem

Time series are to do with communication, for all information can only be transmitted in the form of a time series whether it be through wires in a computer or nerves in the brain. If the system can predict the future states of the time series in a rational manner and this prediction agrees, within given limits, with the actual values when they occur, it can be said that a human or machine understands the time series. Indeed it can be argued that all rational behaviour depends on accurate forecasting of events. Immediate applications of the prediction of time series could be in analysing share prices on the Stock Market; the study of the outbreaks of epidemics in medicine; in crystallography (time series here is, in fact, a spatial series); the analysis of language (this would provide a means of automatic translation); the prediction of eathquakes; even in the choosing of sports teams (a batsman's previous record could provide a means of estimating how well he would perform in the future); but we shall consider a commercial application.

A time series of economical interest is that of the variation of the demand for a particular product over a period of time. Such a time series might be the demand for ice cream over the year which peaks on long hot summer days, or it might be the demand for fuel which peaks on short cold winter days. The particular time series considered here will be that governing the demand for gas over a day. If such a time series is studied a number of peaks will be seen (see Fig. 6.6.) On a weekday, for instance, there will be a small peak around nine o'clock in the morning, another at midday, a very large peak around six o'clock in the evening, dropping to a high plateau which suddenly drops to almost zero at midnight, where it remains until about seven o'clock the following morning. However, on some days, e.g. Sundays, Bank Holidays, etc. there is a large peak at about noon which falls to a fairly high plateau, which again falls sharply around midnight. A further complication is that on some days, especially on some summer days, the high plateau occurs in the afternoon and the demand in the evening might be very small. This might happen on a warm summer day that becomes overcast in the afternoon. A similar effect may be seen in winter when a mild night is followed by a cold day. Under these conditions the demand in the afternoon will be considerably higher than that expected from the demand in the morning. Using this time series as an example it is now proposed to look at a possible filter that could be used in this and similar situations.

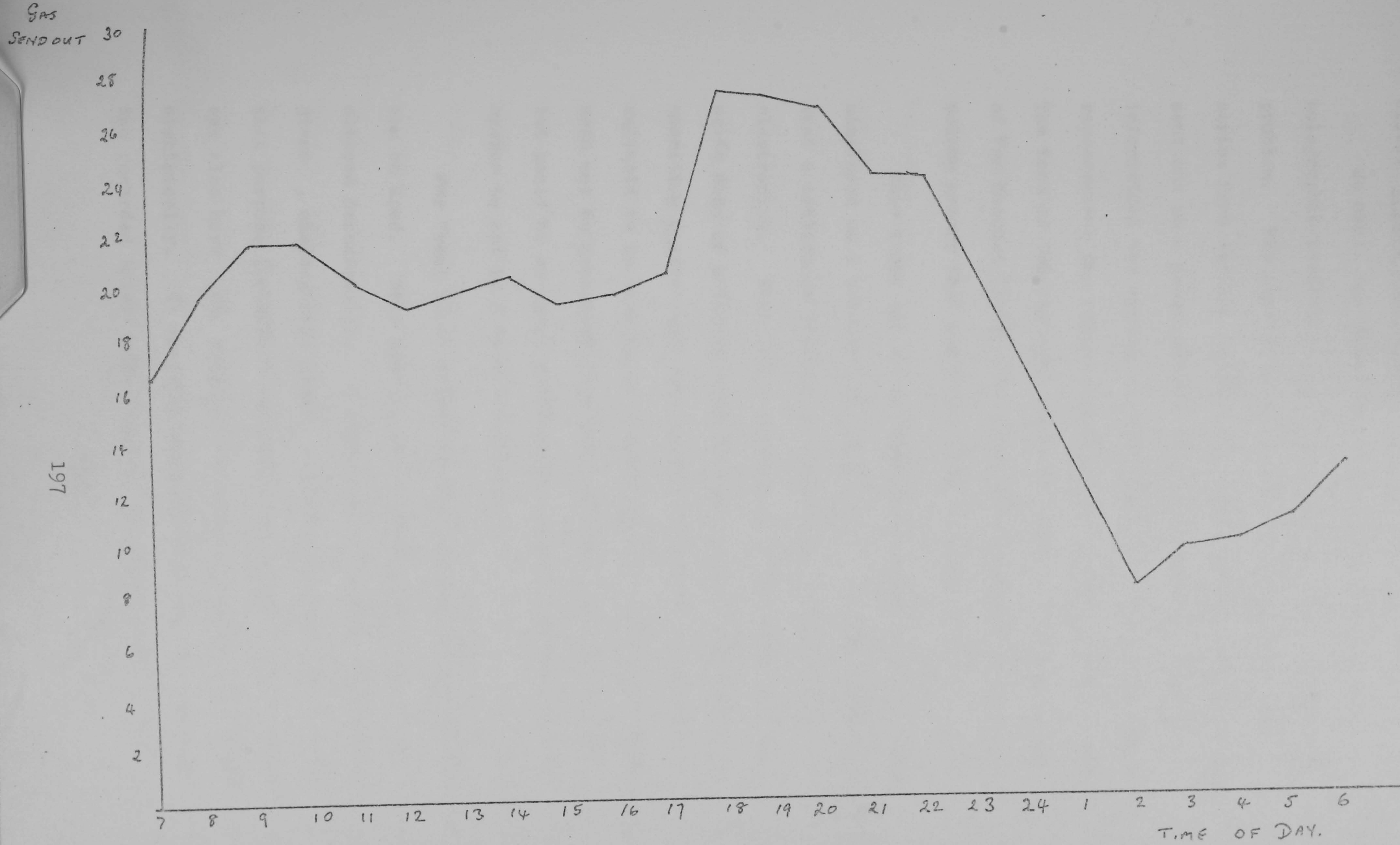

Fig. 6.6. Gas Demand Time Series

6.3.2. A Real Time System

We shall now consider the design of a "real time" holographic predictor capable of handling the gas demand problem. The input, to such a system, consists of time series from various outstations, recording the amount of gas sent out in a given period, usually one hour. From this information the system is required to produce a time series representing the future demand of gas within a given region. The form of this optical predictor would be similar to that of Van Heerden (1968), but would have an input "slide" and volume memory that can be altered in "real time".

This input can be converted into a form suitable to be displayed on a cathode ray tube, and the image refreshed, so that a continuous picture is displayed, by appropriate electronics. This image can then be projected on to the write side of a liquid crystal light valve. The light emanating from the read side would be coherent and thus be suitable to be used in an optical filter. The input image need not be generated from data received from the outside but could be an image produced by a computer, enabling the system to act in a "fast time" mode.

For "real time" volume memories photochromatic glasses can be used. This memory, it is envisaged, will only be altered occasionally. A particular type of photochromatic glass , chalcogenide glass _ , would seem to be ideal for this purpose (OVSHINSKY and FRITZSCHE, 1973). This glass can also have its optical transmission properties altered electrically. It could be arranged that the intensity of the recorded interference pattern is proportional to the frequency of the mutual occurence of the two events. This would be analogous to Uttley's conditional probability machine.

The output of the system would be through a television camera, thus allowing the information to be further processed by a computer and fed back into the system, or simply displayed on a cathode ray tube.

6.3.3. A Learning Filter

Once a "real time transparency" has been realized it is possible to set up a filter which is a "non-linear filter, predictor and simulator which optimizes itself by a learning process" (cf. GABOR, WILBY and WOODCOCK, 1960). The arrangement is shown in Fig. 6.7. Such a filter can use two learning strategies.

The first of these strategies is along the lines of Gabor's filter and entails the comparing of a given length of input with the future values of a training time series. The training time series is recorded on a volume hologram, which enables the filter to examine the correlation of small portions of the time series with a large run of the same time series by rotating the volume hologram. If, for example, the readings of gas demand at ten o'clock, eleven o'clock and twelve o'clock on a particular day are obtained, this can be compared with a hologram containing the readings for the whole of that day, and any points that correlate will show up as bright spots; the distance between these spots indicating the time interval between the two similar points on the time series. Now, if the volume hologram is rotated the sample can be

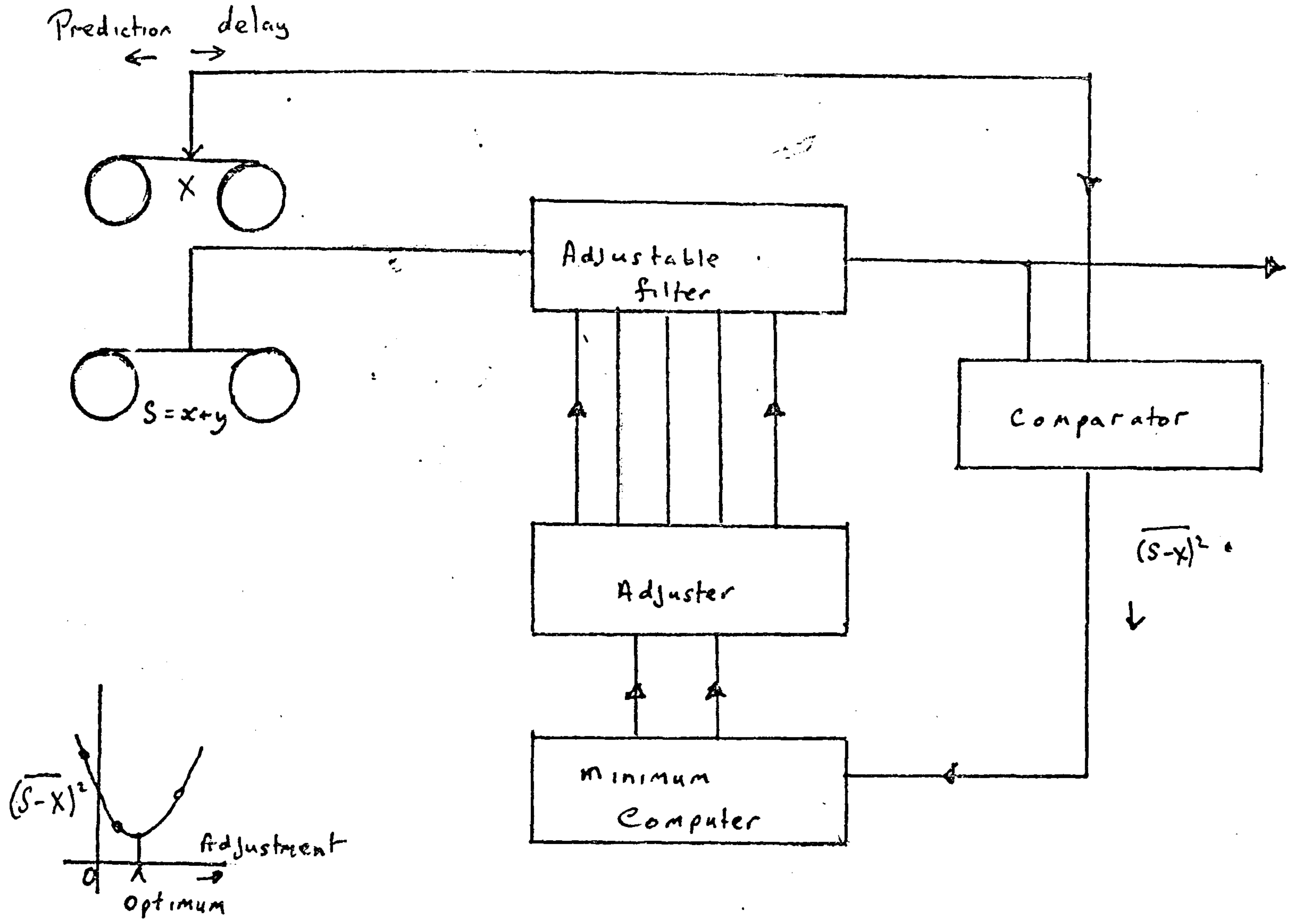

Fig. 6.7.

Learning filter for noise elimination, prediction, or recognition.

(After GABOR, 1954)

compared with a new portion of the time series, say, the day before, and other points that correlate found. Thus, it is possible to compare a given sample with a very long run quickly, and without the danger of mechanical failure inherent in Gabor's design. The system can now go on to compare other samples, pairs of samples (Gabor's diads), trios of samples (Gabor's triads) and so on. All this information can be stored in a computer and subsequently used to generate the coefficients that will enable the filter to give a negative delay to the input, i.e. predict the future gas demand. Such a filter would also be a simulator of the gas supply system. This system can be adapted to analyse the structure of language, it could simulate, for instance, the ability of the ear to understand the spoken word.

The filter could operate in another way. It would be possible to compare, feature by feature, the current time series with a collection of previous standard time series. The decision about which type of time series is to be used could be based on the one that had the largest number of similar features. In its simplest form this would be similar to Uttley's classification machine (UTTLEY, 1956). In this form the filter would simply assign a given section of time series to the appropriate class. A more useful device would be a "conditional probability" machine, to allow for correct classification in the face of "noise". To do this, use can be made of Bayes' rule and the maximum likelihood rule.

Suppose there are z possible classes into which to place the input pattern, X, R_1, R_2,.........., R_r, R_s,.........., R_z.

Then,

$P(r)$ is the probability of the input pattern belonging to R_r,

$P(X)$ is the probability of the input pattern being the particular pattern X,

$P(X/r)$ is the conditional probability of the input pattern being the particular pattern X, given that the input pattern belongs to R_r, and

$P(r/X)$ is the conditional probability of the input pattern belonging to R_r, given that the input pattern is the particular pattern X.

The maximum likelihood decision rule advises that an unknown pattern X should be assigned to the class R_s such that, for all r except r=s,

$$P(s/X) > P(r/X) \qquad \text{(ULLMANN, 1973)}$$

The value of $P(r/X)$ can be obtained by counting. For this a number of specimens of every pattern which can ever occur as an input pattern is required. This makes this method, in most cases, hopelessly impractical because the number of input patterns which actually occur is generally very large. A way round this is to make assumptions concerning the statistics of the recognition classes, and estimate the value of $P(X/r)$ using

$$P(B/A) . P(A) = P(A/B) . P(B) \qquad \text{(BAYES' rule)}$$

combined with the maximum likelihood rule gives the advice to assign X to the class R_s such that, for all r except r=s,

$$P(s) . P(X/s) / P(X) > P(r) . P(X/r) / P(X).$$

Since $P(X)$ is independent of the recognition class, it can be omitted for maximization purposes, and the maximum likelihood rule now becomes, assign X to the sth class such that, for all except r=s,

$$P(s) \cdot P(X/s) > P(r) \cdot P(X/r).$$

One such assumption could be that the pattern elements were statistically independent. For this a collection of specimen patterns from all recognition classes, or a training set, is required. Patterns belonging to both the training set and the class R_r are said to belong to the rth class training set. The number of patterns in the rth training set is designated t_r. Suppose that X is composed of elements $x_1, x_2, \ldots\ldots\ldots, x_j, \ldots\ldots\ldots, x_N$. At the moment only patterns which are binary, i.e. either black or white, are considered. n_{rj} is defined as the number of patterns which belong to the rth training class and have the jth element black (value 1). For all r = 1, ..., z and j = 1, ..., N the value of n_{rj} can be obtained by counting. The quantity defined by $m_{rj} = n_{rj}/t_r$ is subsequently used as an estimate of the conditional probability that the jth element of X is black given that X is a member of the rth class. The quantity $1-m_{rj}$ is used as an estimate of the conditional probability that the jth element of X is white, given that X is a member of the rth class.

If there is no correlation between the values of x_i and x_j in patterns belonging to the rth class, then the ith and jth pattern elements are said to be statistically independent. If it is assumed that, for all r = 1,...., z, the elements of the rth class are statistically independent, then in this case P(X/r) is given by the product

$$P(X/r) = P(x_1/r) \times P(x_2/r) \times \ldots\ldots\ldots \times P(x_N/r).$$

If $x_j = 1$, then $P(x_j/r) = m_{rj} = m_{rj}^{x_j}$, and if $x_j = 0$, then $P(x_j/r) = 1-m_{rj} = (1 - m_{rj})^{(1-x_j)}$. Whether $x_j = 1$ or

$x_j = 0$, it is true that $P(x_j/r) = m_{rj}^{x_j} \cdot (1-m_{rj})^{(1-x_j)}$, and hence

$$P(X/r) = \prod_{j=1}^{N} m_{rj}^{x_j} \cdot (1-m_{rj})^{(1-x_j)}. \qquad 6.3.3.1$$

For simplicity it is assumed that $P(r)$ is the same for all r, or in other words, that the a priori probabilities of all classes are equal. Taking logs of 6.3.3.1 we have

$$\log P(X/r) = \sum_{j=1}^{N} x_j w_{rj} + w_{r0}$$

where $w_{rj} = \log(m_{rj}/(1-m_{rj}))$ and $w_{r0} = \sum_{j=1}^{N} \log(1-m_{rj})$.

To control the trade-off between reject and substitution errors, a reject threshold ρ can be introduced, and the following recognition rule can be applied: assign X to the sth class such that, for all r except r = s,

$$\sum_{j=1}^{N} x_j w_{sj} + w_{s0} > \sum_{j=1}^{N} x_j w_{rj} + w_{r0} + \rho \qquad 6.3.3.2$$

(ULLMANN, 1973)

It is possible, of course, to choose other statistical relations between the elements of the input pattern. A useful assumption is that of normality. This can be expressed as (ANDERSON, 1958; ABRAMSON and BRAVERMAN, 1962; MARILL and GREEN, 1960; ULLMANN, 1973)

$$P(X/r) = \frac{\exp\left(-(\tfrac{1}{2})(X - M_r)^T C_r^{-1} (X - M_r)\right)}{(2\pi)^{N/2} (\det C_r)^{1/2}}$$

In this, X is not restricted to being binary, X and N_r are column vectors

$$X = \begin{bmatrix} x_1 \\ x_2 \\ \cdot \\ \cdot \\ \cdot \\ x_N \end{bmatrix} \qquad M_r = \begin{bmatrix} m_{r1} \\ m_{r2} \\ \cdot \\ \cdot \\ \cdot \\ m_{rn} \end{bmatrix}$$

where m_{r1}, ..., m_{rn} are the average values of the elements in the training set, (see above) and C_r is (an estimate of) the rth class covariance matrix

$$C_r = \begin{bmatrix} c_{r11}, & c_{r12}, & \cdots\cdots\cdots, & c_{r1N} \\ \vdots & \cdots\cdots, & c_{rij}, & \cdots\cdots \\ c_{rN1}, & \cdots\cdots & \cdots\cdots, & c_{rNN} \end{bmatrix}$$

For all i, j = 1, 2,....., N, c_{rij} is the average of $(x_i-m_{ri})(x_j-m_{ri})$ over the training set. Thus, if the t_r patterns constituting the rth class training set are X_1, X_2, ..., X_h, ..., X_{t_r},

$$c_{rij} = (1/t_r)\sum_{h=1}^{t_r} (x_{hi} - m_{ri})(x_{hj} - m_{rj})$$

c_{rij} is a measure of the extent of correlation between x_i and x_j in patterns belonging to the rth class. 6.3.3.2 is only strictly valid when the normality assumption is valid and when the number of patterns in the training set tends to infinity.

Assuming, as before, that the a priori probabilities of all recognition classes are equal, and applying the logarithmic version of the maximum likelihood decision rule, so that X is assigned to the class for which log P(X/r) is greatest, taking logs in 6.3.3.2 and expanding

$$\log P(X/r) = \tfrac{1}{2}(-N \log 2\pi - \log \det C_r - X^T C_r^{-1} X + 2X^T C_r^{-1} M_r - M_r^T C_r^{-1} M_r) \qquad 6.3.3.3$$

In the special case where the covariance matrices for all classes are equal, the terms $-\log \det C_r$ and $-X^T C_r^{-1} X$ can be omitted from 6.3.3.3 since they are independent of r, and the remaining function

$$X^T C_r^{-1} M_r - \frac{1}{2} M_r^T C_r^{-1} M_r \qquad 6.3.3.4$$

is linear in X.

A further simplification is obtained if the covariance matrices for all classes are equal and, for all i,j = 1, ..., N,

c_{rij} = 0 unless i = j, and

c_{rii} = c_{rjj}.

This means that: pattern elements are statistically independent, and the statistical variability of all the pattern elements is equal. In this case C_r^{-1} is scalar and can be omitted from 6.3.3.4 for maximization purposes. Thus, X should be assigned to the class for which

$$X^T M_r - M_r^T M_r / 2 \qquad 6.3.3.5$$

is greatest.

The components of X can be regarded as the coordinates of a point in N-dimensional Euclidean space, and this point is known as the representative point of X. According to the minimum Euclidean distance rule, X is assigned to the sth class such that the representative point of X is closer to the representative point whose coordinates are m_{s1}, ..., m_{sN} than to any representative point whose coordinates are m_{r1}, ..., m_{rN}, for all r except r = s. Ullmann (1973) has shown that 6.3.3.5 is equivalent to the minimum Euclidean distance rule.

In character recognition a change in the overall whiteness of a pattern X, can be represented by the multiplication of X_A by a constant, k. The class to which the minimum Euclidean distance rule assigns an unknown pattern may sometimes be altered by multiplication of the pattern by a scalar. Let $X_B = kX_A$, then the representative point of X_A necessarily lies on the line OX_B, where O is the origin. This error can be removed by replacing the minimum Euclidean distance rule by the rule: assign X to the class R_s such that the cosine of the angle between OX and OM_s is greater than the cosine between OX and OM_r for all r except r = s (ULLMANN, 1973)

OX and OM_r are vectors and the dot product of two vectors equals AB cos Θ where A and B are the lengths of the vectors and Θ is the angle between them. Therefore,

$$\cos \Theta = \frac{X \cdot M_r}{\left(\sum_{j=1}^{N} x_j^2\right)^{1/2} \left(\sum_{j=1}^{N} m_{rj}^2\right)^{1/2}}$$

where Θ is the angle between OX and OM_r, and $X.M_r = \sum_{j=1}^{N} x_j m_{rj}$ is the dot product of X and M_r. For maximization purposes, division by $\left(\sum_{j=1}^{N} x_j^2\right)^{1/2}$ can be omitted, since this is independent or r, and X can be assigned to the class such that $X.W_r$ is greater than for any other class (HIGHLEYMAN, 1961), where W_r is the vector

$$W_r = \left\{ \frac{m_{r1}}{\left(\sum_{j=1}^{N} m_{rj}^2\right)^{1/2}}, \ldots\ldots\ldots, \frac{m_{rN}}{\left(\sum_{j=1}^{N} m_{rj}^2\right)^{1/2}} \right\}$$

$\left(\sum_{j=1}^{N} m_{rj}^2\right)^{1/2}$ is the length OM_r, and thus we see that the length of the vector W_r is one unit. Reduction of a vector M_r to a vector of unit length is an example of normalization.

To control the reject/substitution trade-off we can, as before, introduce a reject threshold ρ, and assign X to the sth class such that, for all r except r = s,

$$X.W_s > X.W_r + \rho$$

If this condition is not fulfilled for any class, X is rejected. Note this recognition rule can be applied directly to analogue patterns, whereas the previous result could not. This result could be used when generating holograms by computer. A weight vector, W, could be computed and a hologram of the function $f_1(x,y)$ = W be obtained. This hologram could be used to produce in the output plane the integral counterpart of the discrete dot product W.X, where X = $f_2(x,y)$. This would lead to lower error rates than the simple holographic technique, which is essentially a non-weighted mask technique (ULLMANN, 1973).

6.4. Computer Generated Holograms

A digital computer is often used to calculate the hologram distribution that will produce a desired image (CATHEY, 1974). In generating the hologram, an exact analogy to the optically recorded hologram can be made. The distribution in the hologram plane is calculated, the reference wave added, the sum squared, and the result plotted on a gray scale plotter. This output is then photoreduced to provide a transparency for visible wave reconstruction. In generating a hologram by computer, however, it is possible to correct for possible errors in the reconstruction process (e.g. BURCH, 1967).

6.4.1. Aperture Size and Location Modification

Rather than recording continuous fringes with variations in the transmittance of the hologram, small apertures can be used. The hologram is then either transparent or opaque, and the transmittance varies locally by variations in the size of the aperture. The phase is coded by displacements in the aperture from the regular array. In the earlier work the displacement was determined by the phase at the sample point, but in later work an extrapolation was used to position the aperture according to the phase at the aperture locations rather than according to the phase at the sampling points (BROWN and LOHMANN, 1969). This removed much of the phase distortion.

In computer generation of a holograms, the transmittance level must be digitized and a finite number of samples taken in the hologram plane. Given a fixed number of bits per hologram, a decision must be made how to optimally allocate them between sampling and quantization. It is possible to make the allocation to minimize the mean square errors in the image (GABEL and LIU, 1970). Three types of images have been treated: a known image, a stochastic image, and a sampled stochastic image. Without knowing the type of image, conclusions concerning the optimum procedure are difficult to make. It does appear, however, that in making a computer-generated Fourier transform hologram of a complex object, the quantization should be coarse and more bits allocated to samples. This is generally true for objects with a wide spatial frequency spectrum (CATHEY, 1974).

6.4.2. Multiple Aperture Representation

Another method of constructing a hologram by computer is to code the complex-valued sample using four positive real samples (LEE, 1970). That is, any complex number can be written as

$$g = g_1 - g_3 + ig_2 - ig_4$$

where g_1, g_2, g_3, g_4 are real and positive. Only two of the numbers need be used. This can be implemented in a hologram in a way similar to a diffraction grating. When illuminated with a uniform plane wave, an image wave is produced in the $\cos^{-1} \lambda / d$ direction, where d is the total separation of the four apertures. A path delay of $\lambda/4$ between each aperture produces a phase shift of $\pi/2$ between apertures giving the signs of +1, +i, -1, and -i to the wave amplitudes from the four apertures. In the case of a single aperture per sample point, the path difference in the direction of the image is modified by moving the aperture. In the four aperture per sample case, the apertures do not move, but the wave amplitudes at each are modified (CATHEY, 1974).

Four apertures are not needed. Three apertures can be used if the phase difference between the waves from the three apertures is 2 /3 (BURCKHARDT, 1970). The advantages are that the required memory size and plotter resolution are reduced. The multiple-aperture approach then requires three times more resolution in the direction of the image than a single-aperture technique (CATHEY, 1974).

Chapter 7

LOGIC OF PREDICTION

7.1. Introduction

Prediction by definition is concerned with time and so any logic concerned with prediction must also be concerned with time. Normal logic, i.e. that which is based on Aristotle's logic, only considers the world at one particular instant, i.e. cuts the world into time slices. Thus, it is possible for a statement to be both true and false because its veracity and falsity can occur at different times. The problem is to be able to supply a truth table, so that, given a statement, its value can be assessed at given points of time. Such a statement could be of the form "it is now noon" or "I am pointing to a tree". Further examples of the application of this type of logic can be found in Spencer Brown's Laws of Form (BROWN, 1969).

What are the characteristics of this aspect of time, for time can have many meanings depending on the context, that should be included in any such logic? There appears to be two distinct and contradictory properties of time :-

1) Change - Objects in the external world appear to change, e.g. the acorn becomes an oak tree.

2) Continuity - Those same objects while changing seem to have a continuous existence, e.g. the oak tree has, in some way, a direct, continuous link with the acorn.

The other characteristic of time which is interwoven with the two properties stated above is the unidirectional nature of time. Thus there appears to be a limited window through which any action is possible, which is the opposite of space, i.e. it appears that it is possible to return to any spatial point at any time. This, of course, is probably an illusion as a position in space is only relative, and as the earth, solar system, galaxy, and so on, are moving, in absolute terms (if there are such) it is never possible to return to any given point. However, there is not the same freedom of movement in time as is possible in space. In mathematics and a large amount of physics it is not necessary to regard time in this unidirectional way, it is only in sophisticated disciplines such as thermodynamics and communication theory that the direction of time becomes important. Time as used in astronomy may be different to time as used in thermodynamics. Time in the first case may be defined in terms of the motion of planets, whereas time in the second may refer to the order of events. Thus the two uses of the word "time" may be linked, in the sense that there is an overlap, i.e. the order of the positions of the planets is determined by their motion, but one definition need not be all inclusive, and can in fact be a contradiction of another (WITTGENSTEIN, 1958). The question is why time appears to be unidirectional to the human brain. It could be that the whole of the universe is moving through time as it is moving through space, and it is possible to move back through time in an analogous way to travelling back in space in a rocket. The various logical difficulties that this feat would give rise to would indicate that time would have to have more than one dimension, i.e. if an intrepid time traveller travelled back and altered history, he would have moved across to another time line. The limiting factor on the travelling across time lines could be the energy requirements, just as travelling in ordinary space is limited. If time is such a fourth or fifth dimension it is possible to conceive of an event having an extension in time as well as space, a blip on a celestial, four dimensional, radar screen that is illuminated for a brief period as the display is scanned.

There is another explanation that is possible. Any type of logic works on an internal representation of the external world. Thus, just as dividing the world into discrete spatial objects can be considered arbitrary and due to limitation in the senses, so the apparent contradictions could be due to deficiencies in the sensory system. Thus change can be regarded as occurring very slowly compared with the human reaction time, and that anything occurring any faster would be undetectable (BROWN, 1956). The underlying assumption is that in some sense the world is unchanging, even if this constancy is just in the logic that is used to understand the world. It is possible then that the apparent contradictions in time are merely reflections of the dual mechanism operating in the brain - continuity being a reflection of the continuous function, and change a reflection of the digital process.

7.2. The Concept of Time and Change

The universe for a system is, paradoxically, totally within the system. This universe is constructed from elements derived from two sources, one through the senses of the system from the outside and the other through the "nature" or "fabric" of the system, from within. Thus, for the system, the universe is represented by the system's state. This universe only represents the all-that-there-is universe in so far as the system can be "aware" of the larger universe. The word "aware" is used here in its widest sense, e.g. though a human cannot detect x-radiation for example by use of the senses, he can still be killed by it. Thus the only part of the external universe of interest to the system is that part that can interact with it.

A rational being is one who seeks coherence within the universe. To put it another way, it is one who believes that the universe is coherent, and can thus be understood and controlled. The "universe" is within the being itself, thus it can be said to be trying to achieve coherent states within itself. This definition can be applied to any rational being and avoids defining rationality in terms of any particular type of thinking pattern. The question now to be asked is, why is this internal universe not coherent? It would seem at first sight that this internal universe could be ordered up in any form, and so the rational being simply orders up the required coherent universe and thus no longer has to search for it. To be of interest the coherent universe must survive. What is meant by survival? No man has ever lived more than 150 years. The only thing that can survive in these terms is the species itself or ultimately, life. The reason for this difficulty is that there are systems with a coherent universe within them that no-one would, at first sight, wish to call rational. A thermostat will attempt to keep its internal states coherent, i.e. if the temperature it senses in the room is represented as one internal state, and the required temperature (as set up in its fabric) as another, it will seek coherence in the sense that it will try to make the two the same - i.e. it will act rationally by switching on or off the heating as required. Thus, to be consistent, it is necessary to accept that rationality is a continuum and a thermostat exhibits a rudimentary form of rationality. All systems, however, exist in the real world and external influences can affect coherence of the internal states of the system - a hammer can have quite a dramatic effect on a thermostat. In a large number of control systems these external influences are deliberately minimized (air conditioned rooms for computers, etc.). Even data that is in contradiction with the computer's program is often simply rejected by validation programs.

The other end of the rationality continuum is characterized by systems that are able to take into account external influences and still bring about a desired state. Hidden in the concept of rationality as so far outlined is another concept-desire. The system is rational because it has the desire to try to make its internal states coherent. As the system becomes more and more rational it develops hierarchies of principles, i.e. there will be a set of principles that make the acceptance or rejection of the other sets of principles rational. For example, a thermostat whose output wires are reversed can still act rationally but can no longer control the temperature in the room. A homeostat that has its output similarly reversed still controls the heating system, so that the desired temperature is maintained because it has a principle built into it that if its actions do not bring about the desired results, another strategy is tried. The computer referred to above could not respond to a situation that had not been foreseen by its programme. What the cybernetician is attempting to do is to devise a machine that can act rationally in changing circumstances.

Logic is basically the rules by which propositions are manipulated. The propositions themselves have nothing to do with logic. Thus the whole of Euclidean geometry is based on five axioms, the arbitrariness of the fifth is shown by the development of non-Euclidean geometry. The only rules for the generation of these axioms are that they are not mutually contradictory, nor is one axiom deducible from the others. Once these axioms are generated, whether they be axioms in mathematics, or self-evident truths in rational philosophy, they can then be used to generate a system. This generation of a system is simply the making explicit of what is implicit in the axioms, in a similar way to the conjurer producing streamers from a hat after they had been placed there in the first place. Thus, to a powerful enough mind, all that would be required would be the axioms and the whole system would become apparent, - there would be no need of logic or mathematics (AYER, 1971). There would be no need of time either. Now, the problem is whether these axioms are true or simply logically valid.

If a system can be generated from a series of axioms, another system can be generated from the negation of some, or all, of those axioms. The problem is how these particular axioms relate to common sense reality. Avoiding for the time being the difficulties of the empiricist's position, it is the normally held view that these fundamental axioms can, by a process of induction, be derived from experience. Thus by applying a particular law, which has previously been derived from experience, to a particular situation, the truth of that particular law can be tested, and if found wanting can be changed. Thus there are two sets of logical propositions. There are those that are derived from axioms - analytical statements which can be obtained without reference to experience (a priori) and those which are derived from experience - a posteriori synthetic propositions. Thus it is possible to generate a system in which unsupported objects fall to the ground, and equally possible to generate a system in which they rise. Each of the systems is logically valid, and experience indicates which is true. Analytical statements can have an absolute certainty as long as the logic is valid, whereas synthetic statements cannot. No-one has seen all the apples that have fallen off the trees.

The trouble is that experience is not a wholly objective affair. Events are experienced through the senses which, like all information channels, have a finite bandwidth, and are interpreted according to past experiences. Kant was the first to point out that all humans could be so pre-wired that logical necessity and psychological necessity were one and the same thing. Hume took the empiricist's position to its logical conclusion and found that he could not justify even such "common sensical" notions as cause and effect, or indeed any relational quality. Kant argued that it was perfectly possible that cause and effect, or other relationships, did not exist in the external world, but that the grid to interpret the world was pre-wired into every human, or to be more exact every rational human, so that no-one could see the world in any other way, just as no-one can imagine, visually, four dimensional space. As this wiring was there before anyone experienced the world it was a priori, but it only became evident as one experienced the world, so it is synthetic. Thus Kant was arguing that rationality was a function of the fabric of the brain (or psychology) and a human being could only be of the form of a rational being.

The position now reached, or which would be reached if the argument was pushed to its logical conclusion, is that of solipsism, i.e. the universe has become totally egocentric. This is the fate of all philosophies which make the subject-object distinction their starting point. Can there be any other type? A large number of information storage devices have the information stored externally to the data processing unit, whether it is a computer with its external storage discs or a classics scholar and his library. This concept can be taken further, a person might notice a scratch on seeing a car, but might only be able to draw the merest outline from memory. It would also seem a logical assumption for a rational being to make that it, itself, is constructed in a way that is coherent with the rest of all-that-there-is. Thus the distinction as to what is part of the system and what is not becomes now a matter of to what purpose such a distinction is to be put. Consider the pen with which an author writes. While he writes it is part of the system called the author, it certainly is not when it is lost in the street, or is it? A tooth is part of the human body until it is pulled. It should be noted that time has a definite part of this system. This concept can be taken further. Consider a babe born into the world. At first it is totally self-centred and knows only itself and its wants. Gradually it acquires knowledge of the world and becomes able to control its environment. It sucks the world into its own universe. Eventually, if it lived long enough, it would suck in enough to contain all reality in its own universe. At the same time everyone is trying to do the same thing. Thus an on-going process is generated, seeking a unity in time, the system is dynamic, rather than the static one generated by the Chinese box form of logic. A distinction, made in order to "understand" the world, is a contradiction that must be removed at some later date. This is not a function of the fabric of the rational being but a function of the definition of a rational being.

Logic in these terms was used by Hegel to be synonymous with metaphysics. This view can be illustrated by taking an example from Russell (1946). "The view of Parmenides, that the One, which is alone real, is spherical. Nothing can be spherical unless it has a boundary, and it cannot have a boundary unless there is something (at least empty space) outside it. Therefore to suppose the universe as a whole to be spherical is self-contradictory. To take an even cruder example. One can say, without apparent contradiction, that Mr. A is an uncle; but if one was to say that the Universe is an uncle, this would lead to difficulties. An uncle is a man who has a nephew, and the nephew is a separate person from the uncle; therefore the uncle cannot be the whole of Reality. This example could also be used to demonstrate the Hegelian dialectic, which consists of thesis, antithesis and synthesis. The thesis is that the Universe is an uncle. The existence of an uncle implies that of a nephew. Since nothing exists except for the Universe as a unity, and there must be a nephew, therefore the Universe is a nephew, which is the antithesis. This however has the same objections as the view that the Universe is an uncle, therefore one is forced to conclude that the Universe is both uncle and nephew - synthesis. But this synthesis is still unsatisfactory as the uncle must have a brother or sister who is the parent of the nephew and so the Universe is enlarged to include the brother or sister along with their spouse, and so on. For Hegel the most real characteristic of an object is its notion, i.e. the conceptual representation of it within the rational being and the most real thing as the Notion which was similar to Aristotle's absolute being thinking about pure thought. Throughout this whole process there is an underlying assumption that nothing is really true unless it is about Reality as a whole.

"For this underlying assumption there is a basis in traditional logic which assumes that every proposition has a subject and a predicate. According to this view, every fact consists in something having some property. It follows that relationships cannot be real, since they involve two things, not one. "Uncle" is a relation, and a man may become an uncle without knowing it. In that case, from an empirical point of view, the man is unaffected by becoming an uncle; he has not quality that he did not have before, if by quality is understood something necessary to describing him as he is in himself, apart from his relation to other people and other things. The only way in which the subject-predicate logic can avoid this difficulty is to say that the truth is not a property of the uncle alone, or of the nephew alone, but of the whole composed of uncle-and-nephew. Since everything, except the whole, has relations to outside things it follows that nothing quite true can be said about separate things, and that in fact only the whole is true. This follows directly from the fact that 'A and B are two' is not a subject-predicate proposition, and therefore on the basis of traditional logic, there can be no such proposition. Therefore there are not as many as two things in the world; therefore the Whole, considered as a unity, is alone real".

At this point it might be as well to point out that a certain amount of confusion is caused by the ambiguity of the ontological status of the "Whole". Whether it is merely an intellectual construction within the rational being, as Kant maintains, or is actually the all-that-there-is universe external to the being, and of which its rationality is a reflection, as the rationalist hopes. For a rationalist the second is the position he would adopt, i.e. he would not be able to accept the arbitrariness of the first position - but this of course does not make it true, it is merely an article of faith.

Now, people like Russell find in this issue the question that divides the proponents of analysis from its opponents; again to quote Russell, "Take an illustration. 'John is the father of James'. Hegel and all who believe in what Marshall Smuts calls 'holism' will say: "Before one can understand this statement, one must know who John and James are. Now to know who John is, is to know all his characteristics, for apart from them he would be indistinguishable from anyone else. But all his characteristics involve other people or things. He is characterized by his relations to his parents, his wife, and his children, by whether he is a good or bad citizen, and by the country to which he belongs. All these things one must know before one can be said to know whom the word "John" refers to. Step by step in one's endeavour is to say what one means by the word "John", one will be led to take account of the whole universe, and one's original statement will turn out to be telling one about the universe, and not about two separate people, John and James".

"Now this is all very well, but it is open to an initial objection. If the above argument were sound, how could knowledge ever begin? A large number of propositions of the form "A is the father of B" are known but the whole of the universe is not. If all knowledge were knowledge of the universe as a whole there would be no knowledge". (The question here is what is meant by knowledge and whether knowledge is kept purely within the person, or can be kept within the environment without the knower being aware (conscious) of it. After all a distinction is being drawn here that proponents of holism would not believe to be valid.)

"The fact is that, in order to use the word "John" correctly and intelligently it is not required that everything be known about John, just enough to recognize him. No doubt he has relations, near or remote, to everything in the universe, but he can be spoken of truly without taking them into account, except such as are the direct subject matter of what is being said. He may be the father of Jemima as well as James, but it is not necessary to know this in order to know he is the father of James. If Hegel were right, one could not state fully what is meant by "John is the father of James" without mentioning Jemima: one ought to say "John, the father of Jemima, is the father of James". This still would be inadequate; one should go on to mention his parents and grandparents, and a whole Who's Who. But this results in absurdities. The Hegelian position might be stated as follows: "The word 'John' means all that is true of John". But as a definition this is circular, since the word "John" occurs in the defining phrase. In fact, if Hegel were right no word could begin to have a meaning, since the meaning of all other words would be needed in order to state all the properties of what the word designates, which, according to the theory, are what the word means.

"To put the matter abstractly: one must distinguish properties of different kinds. A thing may have a property not involving any other thing; this sort is called a quality. Or it may have a property involving one other thing; such a property is being married. Or it may have one involving two other things, such as being a brother-in-law.

If a certain thing has a certain collection of qualities, and no other thing has just this collection of qualities, then it can be defined as "the thing having such-and-such qualities". From its having these qualities, nothing can be deduced by pure logic as to its relational properties. Hegel thought that, if enough was known about a thing to distinguish it from all other things, then all its properties could be infered by logic". (Of course, Hegel would reply that the concept of things in themselves was an illusion, thus all its properties could not be discovered, only invented. The only real quality of such an object would be the logic governing its relationship with the whole.)

An analogue of a rational system can be constructed using an Ashby type Homeostat (STEWART, 1976). This would require three boxes, one to represent the environment, one to represent the fabric of the system, psychological needs such as hunger, etc., and a box representing the internal states of the system. To the box representing the internal states the fabric of the system is as much a part of the environment as any external stimuli. The system is made dynamic by the needs of the fabric, i.e. the animal becomes hungry, or by stimuli by the environment which threaten to take the parameters of the system outside safe limits. Thus if a cat puts its paw into a fire, it can be conceived that it will generate a number of strategies to reduce the temperature of its paw to a safe level. The solution is to change its environment by withdrawing its paw from the fire. It could be argued that the cat is only "aware" of the environment through its senses which form part of its fabric, so making the distinction between fabric and external states even more blurred. Given that the fabric needs of the system are taken care of and the environment remains stable, as in a computer centre, would the system revert to inactivity? An animal operates in a logical environment, in the sense that its actions necessarily bring certain results. Crudely put, the population of foxes are controlled by the population of rabbits. Thus, if the population of foxes increases, more rabbits are eaten, so the population of rabbits decreases, meaning that there is less food for the foxes, so causing the population of foxes to decrease. The question is whether there is any principle which is at the basis of intelligent behaviour, but which is not a function of the fabric. What would this principle look like?

It can be noted in passing that if there are two or more possible states which are stable in the above analogue, the one chosen will depend on the history of the machine, i.e. the states it had acquired before commencing on the solution of the next problem.

7.3. Laws of Form

Spencer Brown (1969) dealt with similar problems to those discussed above in his book "The Laws of Form". The basic theme of the book is that the very act of making "distinctions" creates a universe. It does this in two ways. The distinction can draw a boundary around an object, limit it, or negate it, in the sense that it also deliminates the area of the universe that is not part of it, e.g. circumference of a circle in a plane. Alternatively, it can mean that the very act of dividing off part of the universe means that the rest of the universe can be reconstructed within the severed area, e.g. the external and internal environments of a living organism.

It is claimed that by studying the representation of such a severence it is possible to reconstruct the basic form underlying linguistic, mathematical, physical and biological science. It is possible to take any form - there is no reason for taking any particular universe - but the laws relating to such forms will be the same in any universe and so, by using mathematics, it is possible to go beyond appearances and actually see the structure of all creation. Thus the book hopes to separate what are known as the algebras of logic (Boolean) from the subject of logic and re-align them with mathematics, and so enable the use of an arithmetic. The discipline of mathematics is a way of revealing subjective knowledge of the structure of the world only because of the common ability of people to reason and compute.

The book attempts to derive all the necessary formulations, stage by stage, going from the arithmetic to the algebra. A distinction is made between proof of a theorem and demonstration of a consequence. A proof appeals to a system outside the system in which it is required to prove the theorem - i.e. requires a meta language - a consequence can be completely developed within the system. The question is why the proof of a theorem is regarded as amounting to the same degree of certainty as the demonstration of a consequence. The answer seems to lie in the concept of experience, particularly in the experience of counting, and through this experience people become quite certain, in their own minds, of using it as a substantiate proof. But since the procedures of the proof are not themselves yet codified in a calculus, the certainty at this point must be deemed to be intuitive. A demonstration can be achieved simply by following instructions, even in an unfamiliar system. But in proving a theorem, if the proof is not a codified structure in the form of a calculus, there must be familiarity with, or experience in, whatever it is that is taken to be the ground of the proof, otherwise it will not be recognized as a proof. Thus the consequences of the theorem are probably known from "experience", or are determined by the purpose to which the system is to be put. It is necessary to see the relevance, in respect of whatever statement it is desired to justify, of some fact in full view, and of which one is already constantly aware. Whereas one may know how to undertake a search for something one can not see, the subtlety of the technique of trying to find something which one already can see may be more difficult to discover. This can be seen further in the fact that few useful theorems in mathematics remain unproved; whereas few useless ones remain proved. Their apparent uselessness is not exactly a reason why such theorems cannot be proved, but is a reason for supposing that if a valid proof were given today, nobody would recognize it as such, since nobody is yet familiar with the ground on which such a proof would rest.

One of the motives that prompted Spencer Brown to the development of the calculus was the hope of bringing together the investigations of the inner structure of our knowledge of the universe, as expressed in the mathematical sciences, and the investigations of its outer structure, as expressed in the physical sciences. Here the work of Einstein, Schrödinger and others seems to have led to the realization of an ultimate boundary of physical knowledge in the form of the media through which we observe it. It becomes apparent that if certain facts about common experience of perception, or what could be called the inside world, can be revealed by an extended study of what is called, in contrast, the outside world, then an equally extended study of the inside world will reveal, in turn, the fact, first met with in the world outside: for what is approached, in either case, from one side to the other, is the common boundary between them.

To express this in a slightly different way Laing (1967) suggested that what in empirical science was called data, being in the sense arbitrarily chosen by the nature of the hypothesis already formed, could more honestly be called capta. By the reverse analogy, the facts of mathematical science, appearing at first sight to be arbitrarily chosen, and thus capta, are not really arbitrary at all, but absolutely determined by the nature and coherence of our being. Thus the facts of mathematics may be considered to be the real data of experience, for only these appear to be in the final analysis, inescapable.

An interesting facet of Spencer Brown's Laws of Form (BROWN, 1969) is the extension of the algebra to include equations of degree greater than 1 by the introduction of time. Thus the value of a point on the plane where a distinction is made can oscillate between two values, the marked and unmarked state, 0 and 1 and so on, in a third dimension, time. This introduction of time also introduces frequency, and necessarily introduces velocity, i.e. the wave travels with a given speed and direction. Using these concepts it is then possible to construct memory and modulation, i.e. counting circuits. Spencer Brown claims that one such circuit is the first device to count purely by logic (switching circuits) with no artificial time delays. Such a claim depends on what is meant by time delays, for a point in the plane described above must take a particular value for a finite time - otherwise it could not be detected - so that some form of delay must be used, even if it is merely the pulses, which it counts, controlling the action of the switches.

There are a number of consequences for cybernetics in the "Laws of Form".

The question of dominant and recessive values brings to mind the distinction of dominant and recessive characteristics in genetics.

Spencer Brown stated that the world as described by the Physicist consists of a number of fundamental particles which, if shot through their own space, appear as waves, and are thus of the same laminated structure as pearls or onions, and other wave forms called electromagnetic which it is convenient, by Occam's razor, to consider as travelling through space with a standard velocity. All these appear bound by certain natural laws which indicate the form of their relationship.

The Physicist himself who describes all this is, in his own account, himself constructed of it. He is, in short, made of a conglomeration of the very particulars he describes, no more, no less, bound together by and obeying such general laws as he himself has managed to find and record.

Thus we cannot escape the fact that the world as known is constructed in order (and thus in such a way as to be able) to see itself.

But in order to do so, evidently it must first cut itself up into at least one state which sees, and at least one other state which is seen. In this severed and mutilated condition, whatever it sees is only partially itself. We may take it that the world undoubtedly is itself (i.e. is indistinct from itself), but in any attempt to see itself as an object, it must, equally undoubtedly, act so as to make itself distinct from, and therefore false to, itself. In this condition it will always partially elude itself.

There is nothing logical in the reason why the universe should behave in this way. The universe could be a perfectly constructed clock, and perhaps some are, but no one or no thing would be aware of it.

Having divided the world up it is necessary to reconstruct it, and for this Spencer Brown provides his calculus. To reunite this divided world it is necessary to take the pieces from the external world, not to make a new jigsaw pattern. It is this interaction with the environment that enables a system to be intelligent or rational, along with the need to reduce everything to the simplest form (two crosses deep, and containing not more than two appearances of any given variable).

7.4. Axiomatic System in Biology

Woodger (1951) has attempted to develop an axiomatic system that would provide an analogous mathematical deductive system for biology to that which is being used in physics. It is in biology that these logical difficulties with time are most apparent, in Newtonian physics, for example, a film of the motions of heavenly bodies could be reversed without any apparent differences, but a film of evolution would appear to be wrong. Woodger introduced the concepts of time slice and time stretch, i.e. an organism is made up of a whole series of moments, e.g. the organism called Sir Walter Scott is made up of a whole series of moments such as the author of Waverley, the author of Ivanhoe, and so on. These moments are labelled time stretches because they stretch over a period of time. Thus the four-dimensional organism can be built up from slices, in a similar manner to a three-dimensional picture of an organism built up by examining two-dimensional slices of it under a microscope. Thus a logic can be built up in which events or objects have extension in time as well as space.

The difficulty is in making the definition of a moment unambiguous. Woodger (1939) attempts to do this by making moments have no duration in time, i.e. one of the postulates in the system states that x is a momentary thing if, and only if, x is before x in time. Thus, everything is made up of these momentary events. This is very much like the spatial monads in Liebnitz, i.e. though they have no spatial extension, if they are packed closely enough together they give the appearance of extension. The reason for this approach is to enable the statement that an event x occurs before an event y. This is achieved by combining the above postulate with the postulate which states that, of any two momentary things, one is always before the other in time. This follows from the first because, by definition, the only case where one momentary event does not occur before or after another is if they occur together, in which case by the first postulate one still occurs before the other. Thus it can be stated that x is before y in time if, and only if, every momentary part of x is before every momentary part of y in time. The trouble is that "time" defined in this way has no longer the meaning "time" has in ordinary language. This always seems to happen when an attempt is made to make language into an axiomatic system.

A possible way out of this dilemma is to define extension in both time and space in terms of continuous functions and invoke the notion of limits as used in differential and integral calculus.

7.5. Cellular Automata

Cellular automata were first defined by von Neumann (1966) and he went on to define a particular two-dimensional automaton with twenty-nine states per cell. He wanted to show that this 29-state cellular space was both a universal computer and a universal constructor. A universal computer - constructor has the two following properties: first, it can perform any computation (i.e. can simulate any Turing machine), and second, given the description of any "quiescent" automaton, it can construct that automaton, it can construct that automaton in a designated "empty" region of the cellular space. Self-reproduction follows as a special case of universal construction.

Cellular automata are derived from the Turing machine (TURING, 1937) which was a conceptional device which could notionally read and write binary digits on paper tape. A Turing machine consists of three parts: (i) a finite automaton, (ii) a potentially infinite tape, (iii) a device for reading, printing a new symbol on, and moving the tape. The tape is divided along its length into squares which either contain a symbol or are blank. These squares are read one at a time by the reading device, and, depending on the symbol on the square and the internal state of the automaton, the old symbol on the tape could be overwritten and/or the tape moved one square to the left or right, or stopped. The internal state of the automaton could also be changed. Turing investigated the conditions under which a finite part of an infinite sequence could be generated by the machine when it was provided with a finite set of instructions.

In cellular automata a co-ordinate system is assumed and the programme is executed at every cell simultaneously, and not sequentially, as in the single arithmetic unit of the typical computer. An example would be J.H. Conway's game Life (see for example GARDENER, 1970). Transition rules, which are applied simultaneously to all the cells, specify the configuration for the next interval of time.

It has been argued (MACKAY, 1976) that the concepts of cellular automata provide a basis for a better understanding of crystallographic structure. The traditional formalization of crystollography into the 230 space groups cannot handle occurences of pseudosymmetry and local symmetry adequately. He argues that a regular structure should mean one generated by simple rules and that the list of rules regarded as simple and "permissible" should be enlarged. Cellular automata, such as Conway's game show an immense variety of behaviour, suggesting aspects of reproduction, growth and evolution which are encountered in systems of real cells. They stress the kinematic and configurational, rather than the dynamic or energetic features of a system, and deal with information rather than energy. They are, thus, more apt for the modelling of very complex systems, with large numbers of local minima in the free energy landscape, where the system cannot easily 'find' the lowest minimum. Meta-stability is enough.

The cellular automaton consists of (i) a space, (ii) an initial configuration, (iii) an alphabet of components,

(iv) a grammar of syntatic rules and (v) a transition scheme for applying these rules. Given the state at one instant, the state of the next can readily be found and thus, by repeated induction, the behaviour of the system in time (or space). The rules may depend only on the state of the one cell to which they are being applied, or they may involve the states of other cells in more complex ways. There may be snatches of program containing, for example, conditional or probabilistic statements.

The rules describing the morphology of growing crystals are more like those of the 'Life' game. For example, new molecules may bombard the surface of a growing crystal. If it finds itself alone on the surface it re-evaporates. If it lands in a corner, or in a re-entrant angle, then it sticks. If it arrives in the angle of a step it moves along until it reaches a re-entrant corner, and so on. Recast in this form there is an evident analogy, but the significance is that a set of simple rules (a little more elaborate than those of crystallographic symmetry operations) can produce a complex structure. It would then seem possible to produce a set that would generate a convincing snowflake. Mackay (1976) compared a real snowflake with two- and three-dimensional patterns generated by S. Ulam (Schrandt and Ulam, 1970) using a few simple transition rules. These define how one molecule adds on to those which arrive earlier. In deciding whether an arriving molecule sticks or re-evaporates, consideration must be given to the neighbourhood and the notional 'vapour pressure' which it represents in a real ice crystal.

Codd (1968) reduced the number of states per cell to eight. Of these, four (0, 1, 2, 3) are mainly structural while the otho four (4, 5, 6, 7) are used for signalling. State zero (0) is the blank state. State one (1) is used to mark out a bi-directional transmission path through the cellular space. Such a path is ready to conduct signals when it is insulated or "sheathed" by neighbours which are in the sheathing state (2). State three (3) is used for gating functions. Two of the signal states (4, 5) are used for information transmission and processing. The direction of a signal down a transmission line is determined by means of a blank state (0); for example, "04" moves to the right, "40" moves to the left. The signal state six (6) is used to cause a sheath to be formed on the two sides of a transmission line of ones (compare the myelin sheath surrounding a neuron). The signal state (7) is used to activate an automaton by setting up certain gates and starting the automaton. Thus, the construction of an automaton takes place in three stages. First, the basic structure is laid down in an area by changing certain cells from state zero to state one. Second, the transmission paths are sheathed by the sheathing signal. Finally, the constructed automaton is activated by the activating signal.

Burks (1970) pointed out that there was a similarity between the work of von Neumann and Wiener (see WIENER, 1961). Von Neumann envisaged a systematic theory which would be mathematical and logical in form, and which would be a coherent body of concepts and principles concerning the structure and organization of both natural and artificial systems, the role of language and information in such systems, and the programming and the control of such systems. The theory of automata would thus be an inter-disciplinary subject which combines the viewpoints of logic, communication theory, and physiology, but which should eventually become a separate discipline in its own right. Wiener's cybernetics was similar to this, but there was a difference in approach and emphasis. Cybernetics emphasized servomechanisms and continuous mathematics (analysis), whereas automata theory emphasized digital computers and discrete mathematics (combinatorics and logic). However, Wiener saw that the digital computers were important for cybernetics, and von Neumann wanted to expand automata theory to include the study of continuous mechanisms, he hoped to develop a continuous model of self-reproduction, based on the non linear partial differential equations which govern diffusion processes in a fluid.

It is obvious that the theory of cellular automata can be extended to take account of transition rules based on probability theory and this approach promises to be most fruitful.

R E F E R E N C E S

ABRAMSON, N. and BRAVERMAN, D. (1962) Learning to recognise patterns in a random environment. IRE Transactions on Information Theory, IT-8 No. 5, Sept. 1962, 558-563

ALDRIDGE, E. E. (1971) Acoustical holography. Merror Monograph

ALLPORT, G. W. (1937) Personality. New York: Holt

ANDERSON, T. W. (1958) Introduction to multivariate statistical analysis. New York, London: Wiley

ANDREWS, H. C. (1970) Computer techniques in image processing. New York, London: Academic Press. Also: IEEE Transaction on Computers, C-20 No. 9, Sept. 1971, 1045-1051

ASHBY, W. R. (1952) Design for a brain. London: Chapman and Hall

ASHBY, W. R. (1956) Design for an intelligence-amplifier. Automata Studies. New Jersey: Princeton Univ. Press

ASHBY, W. R. (1956a) An introduction to cybernetics. London: Chapman and Hall

AYER, A. J. (1971) Language, truth and logic. Pelican Books

BAUMANN, E. (1953) The Fischer large-screen projection system (Eidophor). J. SMPTE, 1953, 60, 344-356

BEER, S. (1959) Cybernetics and management. English Univ. Press

BEER, S. (1967) Cybernetics and management. 2nd ed. New York, London: Wiley

BEER, S. (1974) Designing freedom. New York, London: Wiley

BENEDICT, R. (1935) Patterns of culture. London: Routledge

BERGER, H. and DICKENS, R. E. (1963) ANL-6680. Argonne National Laboratory

BOHM, D. (1965) The special theory of relativity. New York, Amsterdam: Benjamin

BOREL (1912) La philosophie mathematique et l'infini. La Revue de Mois, T. 14 10, August 1912, 218-227

BOX, G.E.P. and JENKINS, G.W. (1970) Statistical models for forecasting and control. San Francisco: Holden-Day

BRAITHWAITE, R. B. (1953) Scientific explanation. Cambridge: Cambridge Univ. Press

BRENDEN, B. B. (1967) Acoustical holography, Vol. 1, Chap. 4. New York: Plenum Press

BRENDEN, B. B. (1969) Materials evaluation. 27 (6) 140-144

BRILLOUIN, L. (1922) Diffusion de la lumiere et des rayons X par un corps transparent homogenie. Ann. Phys., 7, (9th ser.), 88

BRILLOUIN, L. (1956) Science and information theory. New York: Academic Press

BROWN, B. R. and LOHMANN, A. W. (1969) Computer-generated binary holograms. IBM J. Res. Dev., 13, 160-168

BROWN, G. H. and SHAW, W. G. (1961) Phototropism (Photochromism). Rev. Pure Appl. Chem., 11(2), 2

BROWN, G. S. (1956) Probability and scientific inference. London: Longmans, Green

BROWN, G. S. (1969) Laws of form. London: Allen and Unwin

BURCH, J. J. (1967) A computer algorithm for the synthesis of spatial frequency filters. Proc. IEEE, 55, 599-601

BURCKHARDT, C. D. (1970) A simplification of Lee's method of generating holograms by computer. Appl. Opt., 9, 1949

BURKS, A. W. ed. (1970) Essays of cellular automata. Urbana, Chicago, London: Univ. Illinois Press

BURT, C. (1941) Is the doctrine of instincts dead? - A symposium I. Brit. J. educ. Psychol., 11, 155-172

BUTTERS, J. N. (1971) Holography and its technology. IEE Monograph. Peter Peregrinus

CALDWELL, P. C. and KEYNES, R. D. (1957) The utilization of phosphate bond energy for sodium extrusion from giant axons. J. Physiol., 1957, 137, 12-13

CATHEY, W. T. (1974) Optical information processing and holography. New York, London: Wiley

CHADWICK, P. (1969) Private communication

CHAITIN, G. J. (1975) Randomness and mathematical proof. Sci. Amer., 232, No. 5, May 1975, p. 47

COCHRAN, G. (1965) New method of making Fresnel transformers with incoherent light. Meeting of Optical Society of America, April 2nd

CRANE, H. D. (1962) Neuristor - a novel device and system concept. Proc. IRE, 50, 2048-2060

DEBYE, P. and SEARS, F. W. (1932) On the scattering of light by supersonic waves. Proc. Nat. Acad. Sci. U.S., 18, 209

DENISYUK, Y. U. (1962) Photographic reproduction of the optical properties of an object in its own scattered radiation field. Sov. Phys. Dok., 7, 543-545

DENISYUK, Y. U. (1963) On the reproduction of the optical properties of an object by the wave field of its scattered radiation. Optics and Spectroscopy, 15, 279

DESCARTES, R. (1912) The philosophical works of Descartes. Edited and translated by E.S. Haldane and G.R.T. Ross. Cambridge: Cambridge Univ. Press

DICKINSON, A. and WATRASIEWICZ, B. M. (1968) Optical filtering applied to postal code reading. IEE/NPL Conference on Pattern Recognition. IEE Conference Publication No. 42, July 1968, 207-237

EDDINGTON, A. (1935) The nature of the physical world. Dent

ELIAS, P. (1953) Optics and communication theory. J. Opt. Soc. Amer., 43, 229-232

ENOCH, J. M. (1967) The retina as a fiber optics bundle. In: Fiber optics by N. S. Kapany. New York: Academic Press

EXELBY, R. and CRINTER, R. (1965) Phototropy (or Photochromism). Chem. Rev., 65(2), 247

FEYERABEND, P. (1974) Consolations for the specialist. In: Criticism and the growth of knowledge edited by I. Lakatos and A. Musgrave. Cambridge: Cambridge Univ. Press

FINK, D. G. and LUTYENS, D. M. (1961) The physics of television. The Science Study Series. London: Heinemann

FREUD, S. (1915) Instincts and their vicissitudes (1915) In: A collection of papers of Sigmund Freud, Vol. 1, translated by Riviere. London: Hogarth (1949)

FRITZLER, D. and MAROM, E. (1969) Reduction of bandwidth required for high resolution hologram transmission. Appl. Opt., 8, 1241-1243

GABEL, R. A. and LIU, B. (1970) Minimization of reconstruction errors with computer generated binary holograms. Appl. Opt., 9, 1180-1191

GABOR, D. (1948) A new microscopic principle. Nature, 161, 777

GABOR, D. (1949) Microscopy by reconstructed wave fronts. Proc. Roy. Soc. (London), A 197, 454

GABOR, D. (1951a) Microscopy by reconstructed wave fronts II. Proc. Phys. Soc. (London), B 64, 449-469

GABOR, D. (1951b) Diffraction microscopy. Research, 4, 107

GABOR, D. (1951c) Microscopy by reconstructed wave fronts II. Proc. Phys. Soc. (London), 64

GABOR, D. (1952) Generalized schemes of diffraction microscopy. Proc. Congres de Microscopie Electronique

GABOR, D. (1954) Communication theory and cybernetics. Trans. Institute of Radio Engineers, CT-1, No. 4, 19

GABOR, D. (1965) Character recognition by holography. Nature, 208, 422-423

GABOR, D. (1966) Symposium on Generalised Networks. Polytechnic Institute of Brooklyn, N.Y. April 12, 1966

GABOR, D., WILBY, W.P.L. and WOODCOCK, R. (1960) A universal non-linear filter, predictor and simulator which optimizes itself by a learning process. Proc. Institution of Electrical Engineers (July 1960)

GAL-OR, B. ed. (1974) Modern developments in thermodynamics. New York, London: Wiley

GARA, A. D. (1977) Real-time optical correlation of 3-D scenes. Apl. Opt., 16, No. 1, p. 149 (Jan. 1977)

GARDNER, M. (1970) Mathematical games - the fantastic combinations of John Conway's new solitaire game "Life". Sci. Amer., 223, No. 4 (Oct. 1970)

GILL, S. P. (1964) The diffraction of light by sound. U.S. Dept. of Commerce Clearinghouse Document AD 603745

GLENN, W. E. (1958) Journal of the SMPTE, 69, 577 (1960)

GRANGER, C.W.J. (1964) Spectral analysis of economic time series. Princeton: Princeton Univ. Press

GRETENER, E. (1956; 1958) Elektrizitätsverwertung, 30, 239 (1956); 33, 172 (1958)

GRIFFITH, J. S. (1971) Mathematical neurobiology. London, New York: Academic Press

HAMANN, O. F. (1966) Random access light valve study, Rome Air Development Center. Tech. Rep. RADC-TR-65-451

HARLOW, H. F. and ZIMMERMAN, R. R. (1959) Affectional responses in the infant monkey. Science, 130, 421

HAWKINS, D. (1964) The language of nature - an essay in the philosophy of science. San Francisco, London: Freeman

HEMPEL, C. G. (1966) Philosophy of natural science. Foundations of Philosophy Series. New Jersey: Prentice-Hall.

HIGHLEYMAN, W. H. (1961) An analogue method of character recognition. IRE Transactions on Electronic Computers, EC-10, Sept. 1961, 501-512. See also: U.S. Pat. 2 978 675, April 1961

HODGKIN, A. L., HUXLEY, A. F. and KATZ, B. (1949) Ionic currents underlying the activity in the giant axon of the squid. Arch. Sci. Physiol., 3, 129-150

HOFFMAN, A. et al. (1965) Inverted reference-beam holography. J. Opt. Soc. Amer., 55, 1559

HOFFMAN, A. S. (1966) Electrolytic cell for use as a real time spatial filter. J. Opt. Soc. Amer., 56(b), 828

HOLOTRON CORPORATION, 1007 Market Street, Wilmington, Delaware 19898

HOLT, D. and COLDRICK, J. R. (1969) Acoustical holography and its applications. Ultrasonics, 7. (4), 240-244

HUFFMAN, D. A. (1955) The synthesis of linear sequential coding networks. Proc. Third Symposium on Information Theory, London, 1955

HULL, C. L. (1943) Principles of behaviour. New York: Appleton-Century-Crofts

HYDEN, H. (1970) The question of a molecular basis for the memory trace. In Biology of memory. eds. PRIBRAM, K. H. and BROADBENT, D. E. London, New York: Academic Press

IPPON, E. P. (1967) Diffraction of light by surface acoustic waves. Proc. IEEE (Corresp.), 55, 249

KAPANY, N. S. (1967) Fiber optics. London, New York: Academic Press

KAZAN, B. et al. (1968) Image recording by particle orientation. Proc. IEEE (Corresp.), 56, 338

KELLEY, C. R. (1968) Manual and automatic control. New York: Wiley

KNAPP, R. A. (1965) Techniques for optical analogue multiplication. U.S. Dept. Commerce Clearinghouse Document AD 617961, 1965

KOLMOGOROFF, A. N. (1941) Interpolation und extrapolation von stationären zufälligen folgen. Bull. Acad. Sci. U.S.S.R. Ser. Math. 5, 3-14

KOLMOGOROFF, A. (1942) Interpolation and extrapolation of stationary series. Bulletin de l'Academie des Sciences de l'U.R.S.S. Series Mathematiques.

KOZMA, A. and MASSEY, N. (1966) Bias level reduction of incorent holograms. Meeting of the Optical Society of America. J. Opt. Soc. Amer., 56, 537A (March 16)

KROKSTAD, J. and SVAASAND, L. O. (1967) Scattering of light by ultrasonic surface waves in quartz. Appl. Phys., (Lett.), 1, 155

KUHN, T. S. (1962) The structure of scientific revolutions. Phoenix: University of Chicago

LAING, R. D. (1967) The politics of experience and the bird of paradise. London: Penguin

LAKATOS, I. (1974) Falsification and the methodology of scientific research programmes. In: Criticism and the growth of knowledge edited by I. Lakatos and A. Musgrave. Cambridge: Cambridge Univ. Press

LAMBERT, L. (1960) Advanced radar resolution techniques development of a two-dimensional filter. Columbia Univ. Electron Res. Lab., Tech. Rep. P.2, p. 153 (January 1960)

LAYZER, D. (1967) The strong cosmological principle, indeterminacy, and the direction of time. IN: The nature of time edited by T. Gold. New York: Cornell Univ. Press

LAYZER, D. (1975) The arrow of time. Sci. Amer., 233, No. 6 (December 1975)

LEAN, E.G.H. and POWELL, C.G. (1970) Optical probing of surface acoustic waves. Proc. IEEE, 58, 1939

LEE, W. H. (1970) Sampled Fourier transform hologram by computer. Appl. Opt., 9, 639-643

LEITH, E. (1966) Holography's practical dimension. Electronics, 39, 88 (July 25)

LEITH, E. N. and UPATNIEKS, J. (1962) Reconstructed wavefronts and communication theory. J. Opt. Soc. Amer., 52, 1123

LEITH, E. N. and UPATNIEKS, J. (1963) Wavefront reconstruction with continuous-tone objects. J. Opt. Soc. Amer., 53, 1377

LEITH, E. N., KOZMA, A., UPATNIEKS, J., MARKS, J. and MASSEY, N. (1966) Holographic data storage in three-dimensional media. Appl. Opt., 5, 1303-1311

LEVERENZ, H. W. (1950) An introduction to luminescence of solids. New York: Wiley

LEWIN, K. (1936) Principles of topological psychology. New York: McGraw Hill

LI, C. L. and JASPER, H. (1953) Microelectrode studies of the electrical activity of the cerebral cortex of the cat. J. Physiol. (London), 121, 117-140

LIN, L., PENNINGTON, K. S., STROKE, G. W. and LABEYRIE, A. E. (1966) Multicolor holographic image reconstruction with white light illumination. Bell System Tech. J., 45, 659-660

LIPPMAN, G. (1894) Sur la theorie de la photographie des coleurs simples et composees par la methode interferentieue. J. Physics (Paris), 3, 97

LOHMANN, A. (1965) Wavefront reconstruction for incoherent objects. J. Opt. Soc. Amer., 55, 1555 (Nov. 1965)

LOHMANN, A. W. and ARMITAGE, J. (1964) Shift-invariant optical pattern recognition. J. Opt. Soc. Amer., 54, 1404

LOHMANN, A. W. and PARIS, D. P. (1969) Computer generated spatial filters for coherence optical data processing. Appl. Opt., 7, No. 4, 651-655 (April 1968) See also IBM Journal of Research and Development, 13, No. 2, 160-169 (1969)

LONGUET-HIGGINS, H. C. (1968) Holographic msmory of temporal recall. Nature, 217, 104

LORENZ, K. (1967) On aggression. London: Methuen

LUCAS, R. and BIQUARD, P. (1942) Proprietes optiques des mileux solides et liquides soumis aux vibrations elastiques ultrasondres. J. Phys. Radium, 3,(7), 464

LURIA, A. R. (1973) The working brain. Penguin Modern Psychology Texts.

McCULLOCH, W. S. (1945) The heterachy of values determined by the topology of nervous nets. Bull. Math. Biophysics, 7, No. 2, 89-93

McCULLOCH, W. S. (1956) Toward some circuitry of ethical robots or an observational science of the genesis of social evaluation in the mind-like behaviour of artifacts. Acta Biothforetica, Vol. XI, 147-156

McDOUGALL, W. (1908) An introduction to social psychology. London: Methuen

MACKAY, A. L. (1976) Crystal symmetry. Physics Bulletin No. 27. (November 1976)

MACKAY, D. M. (1956) The epistemological problem for automata. Automata Studies. Princeton: Princeton Univ. Press

MARILL, T. and GREEN, D. M. (1960) Statistical recognition functions and design of pattern recognizers. IRE Transactions on Electronic Computers, EC-9, No. 4, 472-477 (December 1960)

MASLOW, A. H. (1943) A theory of human motivation. Psychol. Rev., 50, 370-396

MASLOW, A. H. (1954) Motivation and personality. London: Harper

MEAD, M. (1935) Sex and temperament. London: Routledge

MEDAWAR, P. B. (1967) The art of the soluble. London: Methuen

MEDAWAR, P. B. (1969) Induction and intuition in scientific thought. London: Methuen

MERLEAU-PONTY, M. (1962) Phenomenology of perception translated from the French by Colin Smith. London: Routledge and Kegan Paul

METHERELL, A. F. (1969) The relative importance of phase 2 amplitude in acoustical holography. In: Acoustical holography, Vol. 1, p. 203, Chapter 14. New York: Plenum Press

METHERELL, A. F. (1969a) Acoustical holography. Sci. Amer., 221 (4), 36-44

METZ, L. et al. (1961) International Commission on Optics Conference on Optical Instrumentation, London, p. 305

MOL, J. C. (1968) The Eidophor system of larger screen television projection. Photogr. J., 102, 128

MONOD, J. (1972) Chance and necessity. London: Collins

MORRELL, F. (1967) Electrical signs of sensory coding. IN: Neurosciences: a study program. pp 452-69. Rockefeller University Press

OKOLICSANYI, F. V. (1939) Televison system. U.S. Patent 2, 158, 990

OVSHINSKY, S. R. and FRITZSCHE, H. (1973) Amorphous semiconductors for switching memory, and imaging applications. IEEE Transactions on Electronic Devices, Vol. ED-20, No. 2, pp. 91-105 (Feb. 1973)

PASK, G. (1975) Private communication

PENNINGTON, K.S. and LIN, L.H. (1965) Multicolor wavefront reconstruction. Appl. Phys. (Letters), 7, 56-57

PIAGET, J. (1953) The origin of intelligence in the child. London: Routledge and Kegan Paul

PIAGET, J. and INHELDER, B. (1956) The child's conception of space. London: Routledge and Kegan Paul

POPPER, K. R. (1974) Objective knowledge - an evolutionary approach. Oxford Univ. Press

PRESTON, K. (1968) An array optical spatial phase modulator. Proc. ISSCC, 100

PRESTON, K. (1969) Optical correlatior modulating light twice in ultrasonic light modulator. U.S. Patent 3, 457, 425

PRESTON, K. (1972) Coherent optical computers. New York: McGraw Hill

PRIBRAM, K. H. (1971) Languages of the brain. New Jersey: Prentice-Hall

RAU, J. E. (1966a) Comparison of coherent illuminated images. J. Opt. Soc. Amer., 56, 541A

RAU, J. E. (1966b) Detection of differences in real distributions. J. Opt. Soc. Amer., 56, 1490-1494

RAU, J. E. (1967) Real-time complex spatial modulation. J. Opt. Soc. Amer., 57, 798-802

REE, J. (1974) Descartes. London: Allen Lane

REIZMAN, F. (1969) Optical spatial phase modulator array. Proc. Electro-opt. Syst. Design Conf., New York

ROSENTHAL, A. H. (1963) Correlation system for radar and the like. U.S. Patent 3, 088, 113

RUSSELL, B. (1921) An analysis of mind. The Muirhead Library of Philosophy of Science

RUSSELL, B. (1946) History of Western philosophy. London: Allen & Co.

RUSSELL, B. (1948) Human knowledge: its scope and limits. Allen & Unwin

SCHRANDT, R. G. and ULAM, S. M. (1970) On recursively defined geometrical objects and patterns of growth. In: Essays on cellular automata edited by Arthur W. Burks. Chicago; London: University of Illinois Press

SHANNON, C. E. (1949) The mathematical theory of communication. University of Illinois

SHOLL, D. A. (1956) The organization of the cerebral cortex. London: Methuen

SLOBODIN, L. and REICH, A. (1965) Expansion and compression of electronic pulses by optical correlation. U.S. Patent 3, 189, 746

STEWART, D. J. (1976) Private communication

STROKE, G. W. (1969) An introduction to coherent optics and holography. II edition. London: Academic Press

STROKE, G. W. and LABEYRIE, A. E. (1966) White-light reconstruction of holographic images using the Lippermann-Bragg diffraction effect. Phys., (Letters), 20, 368

STROKE, G. W. and RESTRICK, R. C. (1965) Holograms with spatially non coherent light. Appl. Phys. LNS, 7, (1 Nov. 1965)

THOM, R. (1975) Structural stability and morphogenesis translated by D. H. Fowler. New York: Benjamin

TINBERGEN, N. (1951) A study of instinct. Oxford: Oxford Univ. Press

TURING, A.M. (1937) "On computable numbers with an application to the Entscheidungs problem". Proc. Lond. Math. Soc. (2), 42, 230

TURING, A.M. (1950) Computing machinery and intelligence. Mind, 59, 433-460

ULLMANN, J.R. (1973) Pattern recognition techniques. Reading: Butterworths

URBACH, J.C. and MEIER, A.W. (1966) Thermoplastic xerographic holography. Appl. Opt., 5, 666-667

UTTLEY, A.M. (1956) Conditional probability machines and conditioned reflexes. In: Automata Studies. Princeton: Princeton Univ. Press

VALAVANIS, S. (1959) Econometrics. New York: McGraw-Hill.

VAN HEERDEN, P.J. (1963) A new optical method of storing and retrieving information: theory of optical information storage in solids. Appl. Opt., 2, 387-400

VAN HEERDEN, P.J. (1968) Foundations of empirical knowledge. Wistik Wassenaar

VON NEUMANN, J. (1966) Theory of self-reproducing automata edited and completed by Arthur W. Burks. Urbana: University of Illinois Press

VON WRIGHT, G.H. (1961) Induction. Encyclopedia Britannica. Chicago

WALTER, W.G. (1953) The living brain. London: Duckworth

WALTER, W. Grey (1969) Neurocybernetics. In: Survey of cybernetics edited by J. Rose. Iliffe Books

WEAVER, C.S. and GOODMAN, J.W. (1966) A technique for optically convulating two functions. Appl. Opt., 5, 1248

WIENER, N. (1948, 1961) Cybernetics. M.I.T. Press

WIENER, N. (1949) Extrapolation, interpolation and smoothing of stationary time series. M.I.T. Press

WITTGENSTEIN, L. (1958) Preliminary studies for the "Philosophical investigations" - generally known as - The blue and brown books. Oxford: Blackwell

WOODGER, J. H. (1939) The technique of theory construction. International Encyclopedia of Science. University of Chicago Press

WOODGER, J. H. (1957) Science without properties. Brit. J. Philosophy of Science, 2, No. 7, 193 (November 1951)

WORLTON, D. C. (1968) Battelle Memorial Institute. BNWL-SA-1772

ZARCOMB, S. (1966) Light modulating means employing a self-erasing plating solution. U.S. Patent 3, 245, 313

ZEMANSKY, M. W. (1957) Heat and thermodynamics. New York. McGraw-Hill