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A REVISED APPROACH TO THE PROBLEM OF INFORMATION OVERLOAD

James R. Taylor

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PROBLEM OF INFORMATION OVERLOAD

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SECTION I

I N T R O D U C T I O N

> Few technological changes have had so profound an effect on the human condition as the development of telecommunications. Man today lives in a maze of electronic signals; it is certain that their influence on the quality of his environment will be even more important in the future than is the case today.
>
> Final Report President's Task Force Communications Policy, 1968.

The Danger of Information Overload in Technologically Advanced Societies

An extraordinary feature of modern telecommunications systems, present or projected, is the rate of technological change by which they are characterized. The introduction of innovations in information transmission has gone from trickle to a flood and threatens to become a torrent. In some ways the field of communication appears to stand now in terms of comparative development where transportation stood nearly a half century ago. The consequence of this evolution is, increasingly, to facilitate immediate and universal information availability. Increases in the rate of transmission of information involving long distance communication result from two related technological developments:

a) increases in channel capacity, i.e., net additions in the volume of information which can be transmitted from one point to another in a given time, and

b) increases in switching capability, i.e., an expansion in the capability to form combinations of internodal links into discriminably different networks.

Growth in channel capacity has resulted from changes in the speed and volume of transmission of signal, additions to the kind of signal that can be effectively transmitted at high speed over long distances - - voice, print, image--and in the quality of representation of the original which can now be achieved. Changes in kind of transmittable signals came about with the introduction of radio (e.g., voice), television (image), and facsimile transmission (print). The establishment of quality of transmission has been a gradual process. In telephone transmission, the goal of engineers has been limited to the "simulation of presence", or a level at which supralinguistic information such as tone of voice, inflection, etc., is transmitted as well as more basic content information. The visual equivalent of simulation of presence remains to be accomplished. However, in every field, the constraints of cost are gradually yielding to technological advance. (1)

Among telecommunication systems, fully switched networks are represented by the postal service and the telephone system. Their flexibility is obtained at a cost: both systems have limited channel capacity. In the past there seems to have been a tradeoff between channel capacity and switching capability. Television, with greater channel capacity than either telephone, telegraph, or post, has been until recently considered primarily an area-wide distribution system. However, while it may have once appeared that greater information transmission could

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(1) It is worth noting, parenthetically, that increases in telecommunicative channel capacity have been accompanied by increases in memory capacity as the variety and fidelity of recording mechanisms has evolved.

be gained either through increases in channel capacity, or through more flexible switching patterns, but not through both, this constraint in turn seems now in the process of being slowly pushed back.

For the individual, the effect of these developments has been that (a) he is more and more the target of a greater number of messages, each having augmented informational content, and (b) because of his access to larger and more differentiated networks, he tends to interact within bigger and more complex systems having greater complexity of organization, correlated with increased variability, and hence with greater information. From all this, it is very clear that technological advances in telecommunication and the amount of information available to the individual are closely associated. The American Committee on Telecommunication of the National Academy of Engineers has recently observed:

> "In a metropolitan area of 5 million population, about 4,800 hours per year per capita (or about thirteen hours per day) are devoted to various modes of reception of social communications, such as reading, television, lecture and discussion, observation of environment, radio, film and miscellaneous... At various estimated receiving rates of nonreduntant bits ber minute, the per capita average reception of information is 100 millions bits per year or roughly 300 bits per minute. It is startling to note how close this is -- within a factor 5 -- to the 1,500 bits per minute taken as the limit of human capacity to absorb information.
>
> Of course, all this information is not at present necessary to the functioning of each individual. Still, as the amount of necessary information per capita grows, the limits of human capacity may be pressed, at least for many." (2)

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(2) National Academy of Engineers (1969)

It has been more than once proposed, and recently strongly reiterated, that the individual's capability to function and to make decisions may break down under the strain of environmental overstimulation.

> "The striking signs of confusional breakdown we see around us -- the spreading use of drugs, the rise of mysticism, the recurrent outbreaks of vandalism and undirected violence, the politics of nihilism and nostalgia, the sick apathy of millions --.... may well reflect the deterioration of individual decision-making under conditions of environmental overstimulation". (3)

Lipowski (1971) has similarly attributed unrest, anomie, and violence to the influence of the widespread exposure of individuals living in affluent, technological and open society to what he terms on "overload of attractive stimuli". The condition in which extreme information processing demands result in temporary or permanent system breakdown has been termed <u>information overload</u>.

The motivation for this paper is to re-examine the existing literature on information overload in order to determine its relevance to the problems of information integration and utilisation in a fully wired society. We will attempt to assess the general applicability of experimentally obtained results, and to propose further, where possible, steps which might be taken to facilitate the more general use of available findings. Finally, where necessary, research will be proposed to extend our knowledge of the adverse effects of augmented information use such as may be present in a society increasingly dependant on telecommunication as its essential means of interaction.

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(3) Toffer, 1970.

the twentieth century, this concern was already well established. As the organization of work activities itself became functionally more complex, there was a natural strengthening of interest in the question of how to analyse the operations performed by men in terms compatible with those used for machines. The school of "scientific management" associated with the name of Frederick Taylor (1907, 1911, 1919, 1947) set about to describe the task-performance characteristics of the human component in systems with exacting precision. Through "time and motion" studies it was hoped that physical tasks performed by humans could be specified in the form of detailed programs of behavior, or "methods", and eventually through systematic training the work efficiency of individuals could be radically upgraded and their notorious unreliability reduced. The emphasis at this time was on energy-transforming tasks.

The original scientific management movement was gradually absorbed into other schools preoccupied with the growing trend to automation. (Diebold, 1952). It soon became evident in any case that Taylor and his followers had seriously underestimated the importance of motivational factors in work performance. However, human factors engineering received a fresh new impetus during the forties and fifties with the emergence of the cybernetic era (Wiener, 1948; Shannon, 1948).
The attention of engineers had in the meantime turned from the energy-processing capabilities of the human organism to his information-processing characteristics. Thus, Sinaiko and Buckley (1957, 1961) state their objective in terms not dissimilar from those of Taylor:

Organization of this Report

The paper is organized in three main sections. In the first, the main concepts of information overload are developed, and the available literature reviewed and criticised. In the second section, a revised approach to the consideration of the human organism as an information processor is developed. The pertinence of the available experimental findings is then evaluated as it pertains to technologically advanced societies. In the third section, the hypotheses are re-stated and a proposal for further research set out. (4)

Situating the Present Report with respect to Previous Research

Modern discussions of the problem of information overload reflect the influence of two basic approaches, one engineering, one psychological, to the study of the human organism as an information processor.

Among engineers, interest focussed on the role of humans as components, within a more complex system. As early as the beginning of

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(4) The review of literature was greatly facilitated by the generous cooperation of Dr. J.G. Miller, who may with some justification be called the "father" of the information overload hypothesis. Dr. Miller permitted us to see an advance copy of the chapter on information overload in his new book on Living Systems. In this chapter, he includes a scholarly and comprehensive review of the literature, from which we have greatly benefited in the preparation of the present report. Fortunately our objectives and theoretical point of view appear to differ sufficiently from Miller's to avoid the risk of excessive duplication. We remain however indebted to Dr. Miller for his kind support.

> "Machines do not operate by themselves. Even in an age of automation men will be involved in one way or another in every system... Men as well as machines are components of systems. Since mechanical and electronic components are now available with very high speeds and capacities, the design engineer's task of integrating men and machines into smoothly functioning systems has become more difficult. If the characteristics -- limitations and capabilities -- of human are known and understood, better man-machine systems will be designed and built."

However, the list of variables to be considered now includes a concern not only for energy transforming constraints (the physical dimensions of the individual, his capability for motor activity, physical needs, and motivational factors (psychological needs, capability for learning, psychological needs, sensitivities to social environment), but also for information-processing constraints (capability for data sensing and processing).

The second major source of interest in information-processing limitations is the result of an enduring interest by psychologists in the processes of perception and the informational determinants of reactions by humans. In addition to these essentially substantive concerns of long standing, another type of psychological influence, programmatic in character, can be discerned. Both the philosophy and the methodology of behavioristic S-R psychology with its inherited model of the reflex arc encouraged the investigation of humans as input-output systems with essentially linear transformational properties (or some stochastic approximation thereof): for every stimulus, a set of responses must be associated. The description of human components in this perspective becomes a problem of the proper description of ensembles of stimuli and responses, and the observation of behavioral correlations between them.

It was because the communication model of Shannon could be made to conform to this traditional psychological paradigm, as well as the more accurate quantification provided by information theory for the description of stimulus ensembles, that the engineering contribution of Wiener and Shannon was so quickly absorbed into psychological research. Much of the work reported in this paper is set within this integrated S-R reflex arc and communication channel model. However, a further effect of the evolution of cybernetic theory has been to provide an alternative model to that of the reflex arc, in simplest form illustrated by the computer which executes a program step by step and which utilizes input data in order to produce an output. The application of this alternative model to experimental research has occurred gradually in several domains of psychological inquiry over the past generation. A notable exception, for some reason, appears to be the field of information overload. A major goal of the present paper is precisely to re-examine some of the available findings within the altered perspective of this other model.

SECTION II

INFORMATION OVERLOAD: HYPOTHESES AND FINDINGS

The Evaluation of Human Channel Capacity

Information theory was seen by psychologists as a tool the existence of which permitted a re-evaluation with profit of some traditional problems in psychology. In his 1951 book, Language and Communication, George A. Miller included a re-interpretation of the results of experiments undertaken by Merkel in 1885. Merkel had found that the reaction time required to make a choice among alternatives was affected by the number of alternatives presented (5). Miller (1951), and subsequently Hick (1952), showed choice reaction time to be a linear function of the informational content of the display (6).

The choice reaction experiment can be interpreted in terms of the Shannon model of an ideal communications system (Figure 1). The sequence of stimulus signals can be seen as equivalent to the message output of the source; the responses of the subject are then interpreted as the message received after being transmitted through the human channel. The capacity of the "channel" is the number of bits which can be transmitted per second, i.e., the number of accurate responses made

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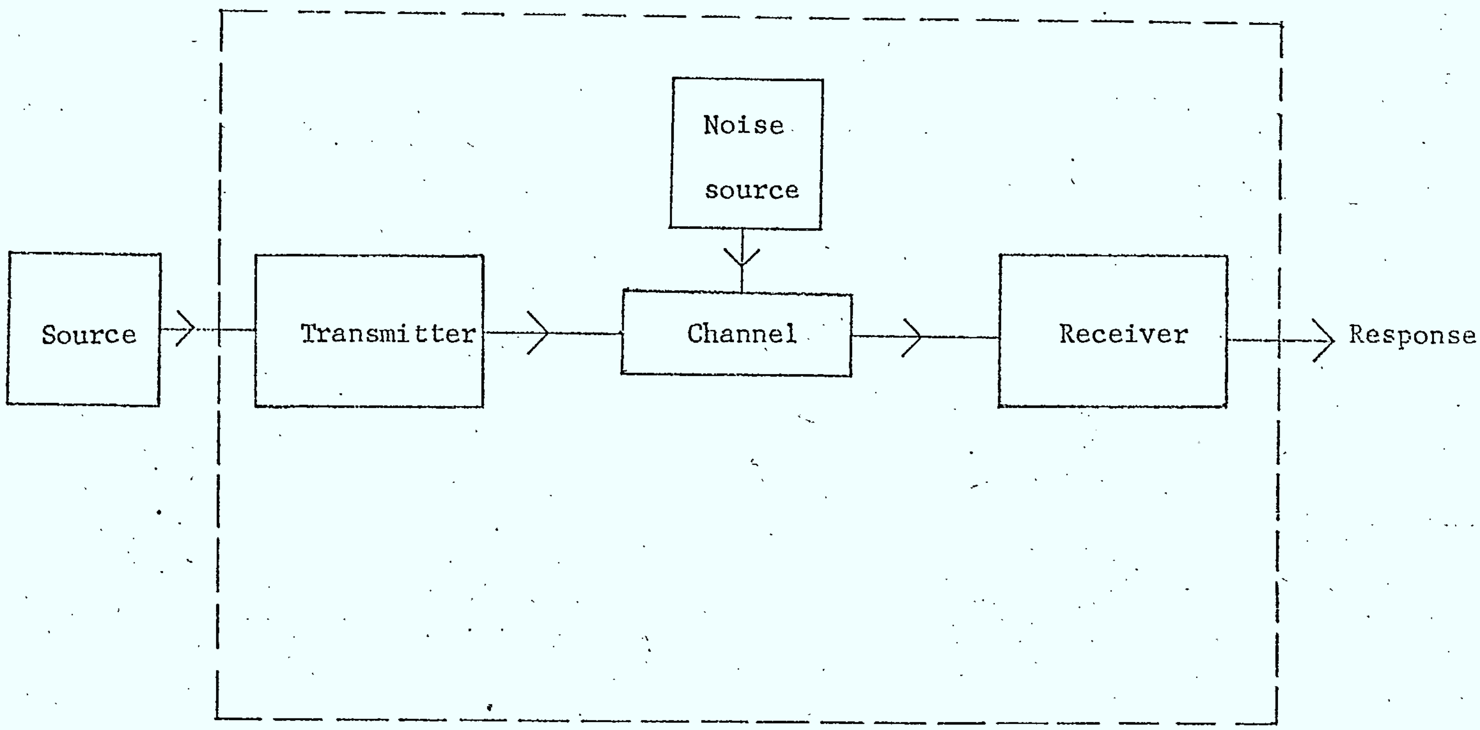
(5) The implied logarithmic relationship had been later observed by Blank (1934).

(6) Choice reaction time is the lag between presentation of stimulus and the subject's response. The subject in a choice reaction experiment must make a separate response, as soon as possible, for each marker as it appears, a single response having been assigned to each signal. The subject has a general idea when the next marker will appear, but he does not know which signal is coming and is therefore uncertain as to which response he must make.

by the subject. The informational content of the messages emitted by the source is a joint function of the rate of emission, the size of ensemble from which the items were drawn, and of the probability of appearance of each.

FIGURE 1



Laming, 1968

Human subject

In the experiment which Hick conducted in 1952, ten pea lamps were arranged in a somewhat irregular circle and the subject was provided with ten corresponding Morse keys. Hick measured reaction times to several series of signal presentations, varying the ensemble size from two to ten. His data again confirmed the assumption of a logarithmic relationship between choice reaction time and the number of alternatives available, when corrected to take into account the temporal uncertainty experienced by the subject as to when the response would be required.

The equation which best fit his data was

$$t(n) = b \log(n+1)$$

where $t(n)$ is the reaction time to one of n equally probable signals, b is a constant, and $(n+1)$ includes a factor to account for the temporal uncertainty associated with the response, which he took to be explainable as the time interval necessary to react to one signal.

In 1953 Crossman made an explicit link between the findings of the choice reaction time experiments and the postulates of Shannon's communication theory, and further observed that human subjects in these experiments could be viewed as channels through which information was transmitted. He went on to point out that the subjects were constrained by a channel which set an upper limit to the rate of response of which they were capable. He used earlier findings to show that the response lag is in fact proportional to the uncertainty in the signal source. Crossman showed in his own experiments that these results still held up when signals were not equally probable.

Hyman (1953) required his subjects to respond to a light by uttering a nonsense syllable. The light appeared in one of several positions. A different nonsense syllable corresponded to each light position. Hyman took into account the uncertainty about when a signal would appear as well as the choice factor. He tested for this by varying the number of equally probable signals, the frequencies of signal occurance (the number of alternatives remaining the same), and first order sequential dependencies, while holding constant the relative frequency of signal occurance.

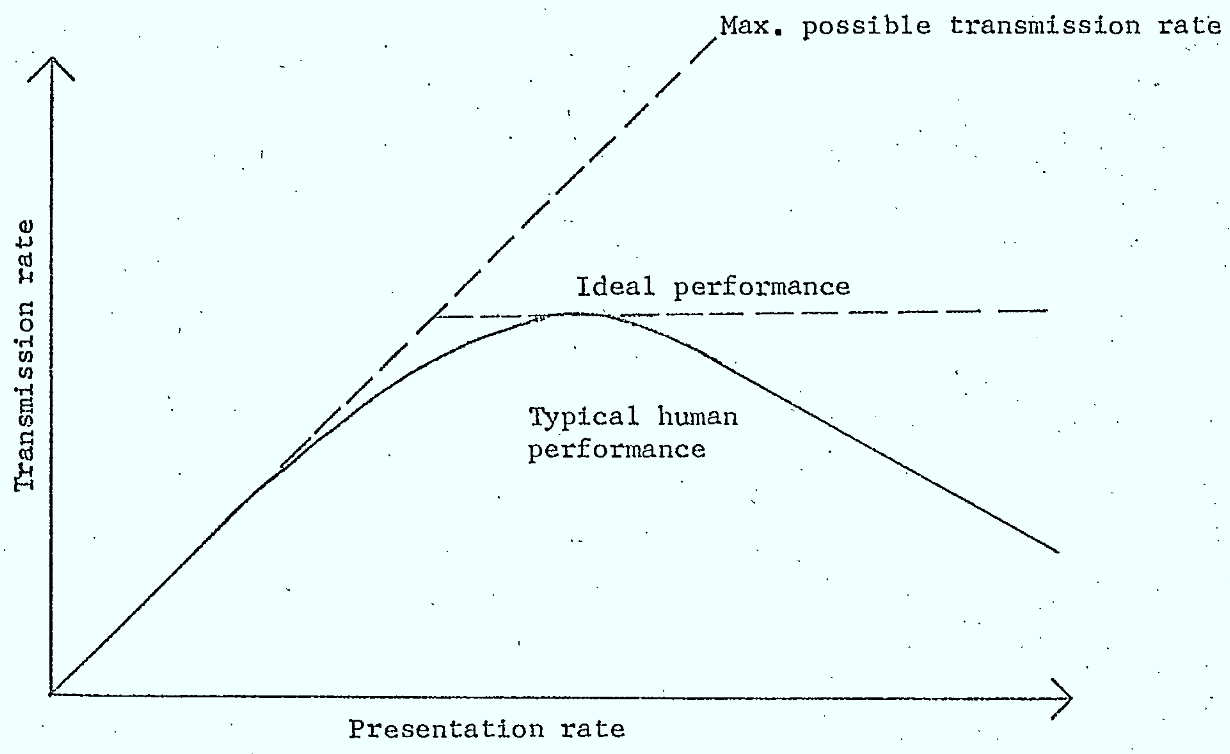
Bricker (1955), reviewing the available choice reaction time studies, again noted that the average reaction time could be plotted as a function of the information in the input: $R = a + bH$, where R is the average reaction time, H is the entropy of the source, and a is the simple reaction time and b the time required to make one binary decision. The notion of simple reaction time is that of a threshold latency, determined in part at least by the time required to marshal <u>any</u> output activity.

From these experiments, it was possible to make a preliminary estimate of human channel capacity in the choice reaction time situation. The results obtained by Merkel (1885), Hick (1952), Hyman (1953), Crossman (1953) and Hilgendorf (1966) indicate this capacity to be of the order of 6 bits per second. However, Klemmer and Muller (1953), and Quastler and Wulff (1955) obtained rates of from 12 to 24 bits per second.

Leonard (1959) and Mowbray and Rhoades (1959) argued from their findings for even higher rates.

As these results indicate, this research also indicated the importance of other factors, of which the most important seem to be the discriminability of the stimuli, the difficulty of performing the response task, and input-output compatibility. In Crossman's (1953) experiment, subjects were required to sort playing cards into various categories (red-black; picturers-plain; suits). Controlling for entropy, differences were obtained which could be explained by reference to difficulty of discrimination. Crossman (1955), Birren and Botwinnick (1955), Botwinnick, Brisley and Robbin (1958), Laming (1962), Shallese and Vickers (1964) produced additional evidence to indicate that difficulty of discrimination can be used to explain apparent differences in channel capacity. Welford (1960) was led from these results to distinguish two stages intervening between presentation of stimuli and response: (a) perceptual identification of the stimulus, and (b) selection of response. The dissimularity of stimuli (Thurmond and Alluisi, 1962), complexity, the presence of noise (Baker and Alluisi, 1962, Broadbent, 1958) affect performance. Other results point to the importance of overlearning (Quastler and Brabb, 1956; Leonard, 1959; Mowbray and Rhoades, 1959, Mowbray, 1964). Fitts and Seeger (1953), Deininger and Fitts (1955), Leonard (1961), Sanders (1967) have discussed the importance of stimulus-response compatibility, arguing that the subject in a choice reaction experiment is essentially faced with a recoding problem, and that choice reaction time should be determined by the difficulty in matching stimulus and response sets

FIGURE 2


Max. possible transmission rate
Ideal performance
Typical human performance
Transmission rate
Presentation rate

(e.g., because of physical contiguity of display unit and motor effector device, similarity in the physical arrangement of display and effector device).

We may summarize these findings by observing that the relationship between the latency of response in choice reaction experiments and the informational content of the stimulus display over a sequence of presentations was generally taken to be well established by the late fifties. This relationship in turn encouraged the acceptance of a model of the human organism stated in a representative way by Broadbent (1958): "A nervous system acts to some extent as a single communication channel, so that it is meaningful to regard it as having a limited capacity".

The Contribution of James G. Miller

Not all the results obtained in experiments with tasks which involved serial presentation of stimuli could be explained by the analogy of Shannon's ideal communication channel. Alluisi, Muller and Fitts (1957) used numerals projected on a screen as a stimulus, varying the number of alternative numerals in the experimental ensemble and the rate of presentation. As the rate of presentation of the stimuli was increased, the subjects began to make increasing numbers of errors, and accordingly the rate of information transmission first leveled off, and then began to decline. (Figure 2)

How to explain the difference in performance between the ideal communication channel and human subjects in these experiments? In a series of articles in the early 1960's, James G. Miller (1960, 1962, 1963a, 1963b, 1964a, 1964b) attempted two objectives: (a) he stated a hypothesis that under certain circumstances the subject should be expected to perform at sub-optimal information-transmission capacities when compared with an ideal channel, and (b) he further set out to show that the results obtained in choice reaction experiments constituted merely one example of a more general principle affecting organisms as simple as the single cell, and as complex as complete societies. He further set out to identify some of the typical symptoms of such communication pathologies, ranging from elementary strategies of adaptation to full escape. The hypothesis of <u>information overload</u> was stated as follows: when input information in bits per second is increased, the output at first follows the input more or less as a linear function, then levels off at channel capacity and finally falls off toward zero. The channel capacity of systems, Miller argued, should differ according to the level of complexity of structure of the organism's information-processing system.

Miller's reasoning may be summarized as follows: The rate of information transmission depends, as we have seen, both on the number of markers per unit time, and on the information carried by each marker. There are inherent limits associated with each of these factors, rate and informational content. First, there is some irreducible time required to process any marker, whatever its content. In addition, following the processing itself, there is in living organisms a further dead time, the refractory period, before the information processor can accept a new marker. Secondly, there are inherent constraints on the organism's coding ability. There are two ways in which markers may be coded (three if we consider the combination of the other two): (a) an amplitude or pulse modulation code, in which the transmission of information depends on whether a signal of a given pattern occurs, and (b) a frequency modulation or pulse interval code in which the transmission of information requires recognition of the length of the interval ocurring between two successive markers. (An exemple of the latter is the familiar "dit -dah" system of radiotelegraphy). In its most elementary form, such a code consists of the presence or absence of a signal during a succession of intervals of equal length. Both these types of code but particularly the second are subject to the following constraint: there is an inevitable variability of performance which means that the actual signal emitted is at best an approximation of the ideal stipulated by the code. We would best consider the obtained set of signals as described by a mean and a variance. If the "jitter" in the transmission of signals is too great (i.e., if the channel is too noisy), or if the signals are too similar to each other for easy recognition, the resulting overlap of variance will inevitably result in numerous cases of misidentification (and attendant reduction in rates of information transmission). Hence there must be some lower limit to the number of gradations which can be discriminated along any dimension of the marker, and an according limit to the amount of information per marker which can be accomodated.

The proposition that as the rate of input of information increases the output does not level off at channel capacity, but rather <u>falls</u>, seems to have been at first a generalization based upon the examination of a variety of empirical findings at several levels of investigation. It is not precisely clear why performance should decline rather than level off at channel capacity, as we should expect if the human in fact conformed exactly to the Shannon model. Miller has suggested that the effect is due to confusion on the part of the organism as it attempts to maintain the pace of activity necessary to handle the increasing load of information being input. The result is a temporary breakdown in the total functioning capability of the organism. This would suggest that Miller regards the organism as essentially an "all-or-none" type of machine, and indeed this interpretation is supported by Miller's position with respect to what he terms adjustment processes, which come into play as channel capacity is neared, and which "enable the output rate... to decline gradually, rather than to fall precipitously to zero immediately whenever the information input rate exceeds the channel capacity." (Miller, forthcoming)

When the model of the organism as a channel is evaluated by reference to specific data, difficulties appear. The simplest living system which is capable of processing information is the cell (and indeed the higher level information macro-processing activities of more complex organism depend entirely on this cellular capability). The cells of the nervous system, neurons, respond to several types of external stimulation such as light, sound, touch, etc.. by emitting a sequence of output pulses or "spikes". Their behavior under differing conditions of external stimulation can be investigated by varying the intensity or frequency of the stimulus.

The problem, however, is that the number of pulses emitted per second is, not necessarily the same as the number of bits, since the code is not available by inspection. Miller's solution to this difficulty is to assume that the number of bits is at least proportional to the number of pulses emitted. On the basis of this assumption, the validity of the overload hypothesis can be evaluated at the level of the cell, even though the actual channel capacity can be at best estimated approximately.

Given these assumptions, there is extensive evidence to support the overload hypothesis at the level of the cell (7). One experiment is sufficient here to indicate the type of result upon which this support is based.

Brock, Coombs, and Eccles (1953) found that when antidromic electrical pulses were input to the motor neuron of a cat at low frequencies (13, 20, and 28 pulses per second) there was a corresponding soma-dentritic spike output rate. When the input pulse rate was increased to 42 pulses per second, output occurred pulses only at every second input. At 61 inpulses per second an output occurred with every third input, at 91 input pulses per second, an output pulse occurred with every fourth input; and so on, with the output pulse rates falling gradually from a recorded maximum of 28 pulses per second.

Some adjustment processes can be at least indirectly inferred from research conducted by Granit and Phillips (1956), who found in

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(7) Reviewed extensively in Miller's forthcoming book Living Systems, chapter 5.

in which subjects rested their fingers on a set of relay armatures, and were required to depress any armature which vibrated. They found no differences in reaction times when the ensemble was varied to include two to eight alternatives. In this case, it may be that high stimulus-response compatibility produced an effect similar to overlearning.

Earlier, evidence was considered which indicated that markers which arrived during the refractory period of the cell would either not be processed at all or, if processed, would elicit a weak response. Vince (1949), using a design which required subjects to respond to dots on a rolling white paper tape by tapping a telegraph key, found that omissions and errors occurred when the next input marker had arrived before the previous response was completed. However, no refractory period as such need be assumed, since subjects were able to maintain correct responses even under conditions of very slight overlap.

Mackworth and Mackworth (1956) found similar evidence to indicate that omissions and errors were correlated highly with the amount of overlap. However, in this experiment the task was rather complex, requiring an identification of six items on each of two cards, and on item by item matching of each of the pairs of items. Webster and Thompson (1953, 1954) also found that the amount of overlap was related to the efficiency of transmission, but concluded that the effect depended on the amount of information associated with each marker: where markers carried little information the effects of overlap were less serious, Broadbent (1958) concluded that two messages could be dealt with simultaneously if they conveyed little information.

Davies and Berman, 1957).

When we turn from applications of the communication channel model to the level of the cell to that of the individual information-processor, somewhat similar difficulties appear. To establish the validity of the hypothesis, it is not enough, as we have seen, to show decrements in output rate as the number of input markers increases. To see this, it is enough to consider the case where the ensemble from which the marker is drawn is reduced to one (i.e., only one kind of signal is ever processed) and the rate of arrival, or length of interval between the arrival of each marker, is constant. In this case, no variety is possible, information input is zero, but if the rate of arrival is set high enough, the organisms capability to transfer the markers from input to output will inevitably be exceeded, and it is possible to obtain the type of experimental results consistent with the predictions of the theory, but which in fact provide no real support for it.

To avoid this risk, it is necessary to show that increases in the size of ensemble have an equivalent effect to those in the rate of input of markers. The attempt to show this has produced some of the major criticisms of the communication channel approach. An experiment by Alluisi, Muller and Fitts (1957) used a random sequence of Arabic numerals projected on a screen at a uniform rate. The experimental manipulation consisted in changes in the ensemble of numerals employed and rate of presentation of markers. The predicted effect appeared in the latter case as predicted, but was less evident in the former. Quastler and Brabb (1956) using experienced typists as subjects presented sequences of letters from the alphabet in various combinations. They found that varying the informational content of the input had little effect. Mowbray (1960) presented numerals to subjects, varying the ensemble from which numerals were drawn from two to ten. Subjects were informed in advance which numerals might appear, and the size of the ensemble. No differences in reaction time were observed. Mowbray and Rhoades (1959), using a format in whcih subjects pushed buttons whenever a light appeared, showed that differences in latency of response between conditions of two and four lights diminished and finally disappeared with sufficient practice.

Miller (forthcoming) has recently observed that these experiments raise again the question of the true ensemble, and as seen earlier, unless the ensemble is known the rate of information transmission cannot be estimated accurately. Miller distinguishes between an "explicit" and "implicit" ensemble: the explicit ensemble is the one which the subject receives from the experimenter, the implicit ensemble he brings with him as a result of a lifetime of training. Thus in the case of numerals and letters there is probably little which can be done experimentally to overcome the subject's own personal implicit ensemble. The role of learning is thus an important determinant which may set limits to the applicability of the communication channel hypothesis: in particular, it is, as the Mowbray and Rhoades results demonstrate, capable of wiping out the original differences in latency of response to ensembles of varying size. This has led Laming (1968) to suggest that in some cases channel capacity may be infinite. He quotes the Mowbray and Rhoades results and also an experiment by Leonard (1959) their work with cells in the cenebellum that when the interval between input pulses was less than 3 milliseconds, every second input elicited an output pulse only 40% of the time, while below 2.2 milliseconds, the intensity of the second output pulse also diminished. Other research appears to indicate similar alternation of strong and weak impulses, prior to more pronounced declines in the transmission rate (Wall, Lettvin, McCulloch and Pitts, 1956).

Other research has indicated that while the neuron appears to be able to discriminate between differences in the intensity of stimulation, and to indicate these differences by changes in the interpulse frequences of its output sequences, there are limits to the resolving power of its discriminatory mechanisms. Mountcastle (1966) has found that the output appears to be able to reflect up to between 4 and 5 categories of input, but that beyond this limit, the cell does not respond separately to further differences in intensity. It will be seen later that this limitation in discriminatory power has an analogue at the level of the human organism, and may provide an explanation for the phonomenon of the "span of absolute judgment", as George A. Miller refers to it.

Additional evidence for the assumption that the number of spikes per unit time is a coding mechanism which represents differences of intensity in the stimulus has been noted by De Valois (1958). More importantly, there is very good evidence to indicate that the information so encoded by reception neuron is preserved intact at higher levels of the nervous system (Jung and Baumgartner, 1955; Tasaki and Davis, 1955). In such systems with numerous cells synaptically linked, the refractory period is however longer than for the individual cell (Mountcastle, The importance of the issue is related to the question of a possible confounding of channel capacity with motor output limitations. If in fact the human organism can, like the cell, deal with only one signal at a time, then it might be argued that some of the findings reported here represent merely the effects of contraints due to the inability of the organism to perform the activity required by the response task in time to prepare for the next marker.

Some evidence of output limits can be found in an experiment by Quastler and Wulff (1955) which involved playing piano notes arranged in a random pattern. Here physical limits imposed by the necessity to move the hand in order to strike lays seem to have been an important factor in rate of information transmission. Up to about twenty keys (roughly two octaves), considerable gains in channel capacity occurred; for a range of 65 keys there were errors even at slow speeds of performance. The same experimenters found similar results using a typewriter. Up to about 16 keys, subjects could achieve about the same speed of output with comparable accuracy, but with 32 keys their performance was strikingly poorer. This result conforms roughly with the ordinary situation faced by a practiced typist, who is accustomed to using about twenty symbols with maximum frequency.

Nevertheless, Quastler and Wulff noted that their results could not have been due to either output constraints alone, since rates could have been improved with practice. The findings suggest the importance not so much of output limitations as of the role of familiar <u>patterns of behavior</u> in the successful accomplishment of the experimental tasks faced by the subjects. This point is taken up for further discussion in the next section.

The question of constraints on rate of information processing due to input limitations has also received attention in the literature concerned with human channel capacity. Here however the type of ceiling effect to be anticipated is no longer associated primarily with rate of processing of markers, but rather with the number of chunks of information which can be apperceived at one instant. The distinction is the same as that made by Jakobson (Jakobson and Halle, 1956; Jakobson, 1964) between selection and combination. Jakobson observes disorders of aphasia, associated with the successful decoding and encoding of verbal information, can be grouped under two headings: similarity disorders -- which occur during the input of information -- and are a product of an inability to select information - and contiguity disorders -- which are associated with difficulties in combining elements into the appropriate output patterns. There are thus two types of relationship among stimuli which organisms must deal with in the process of transmitting information. The effects of information overload on the output, or contiguity, organization of behavior have already been discussed; input or similarity constraints have received equal or perhaps greater attention.

To understand the limits on selection of input, we must first establish the capacity of the organism to discriminate differences. Humans are very good at relative discrimination, which simply implies a comparison along a dimension or dimensions (essentially more or less of some attribute(s)); many tasks however require absolute discrimination, or judgment in the absence of any external reference. George A. Miller (1956), in a famous article "The Magic Number Seven, Plus or Minus Two:

Some Limits on our Capacity for Processing Information", made an extensive review of the literature on this subject, comparing the experimental results across sensory modalities, and arrived at a principle of the span of absolute judgment, which says that "there is a clear and definite limit to the accuracy with which we can identify absolutely the magnitude of a unidimensional stimulus variable". (Miller, G.A.; 1956). The subject's ability to discriminate in absolute terms has been evaluated by Miller in terms of information theory, and he has estimated approximate maxima of 2.5 bits in the judgment of tones (Pollack, 1952; Pollack, 1953), 2.3 bits for judgment loudness (Garner, 1953), 1.9 for judgments of the concentration of salt solutions (Beebe-Center, Rogers, and O'Connell, 1955), 3.25 bits for judgments of visual position (Hake and Garner, 1951). The limits are in all cases approximate: subjects begin to make occasional errors as the number of discriminations required reaches three or four, and increases steadily as the number of discriminations also increases. Such upper limits of discrimination do not depend on the range chosen: Pollack discovered that the same subject who could accurately discriminate 5 high-pitched tones, presented in one series, and 5 low-pitched tones in a second series, could still only distinguish 5 tones when the ensemble included both high-and-low-pitched tones.

A comparison of these results with those mentioned earlier for the single cell, where Mountcastle, Davies and Berman (1957) found that input intensity is coded in 7 discrete steps for thalamic cells, suggests that the limits reported by Miller may have a physiological basis.

The importance of the perceptual constraints imposed by the span of absolute judgment may be better evaluated when placed in the context of the complete perceptual system. First, they apply only to tasks which require absolute judgments; where the problem is one of relative judgment, the same limits do not hold. Secondly, the results reported by G.A. Miller refer only to unidimensional judgments; most sense organs are capable of simultaneous discriminations along more than one dimension simultaneously (leading, Miller to propose a second principle of the span of perceptual dimensionality). Experiments which utilize a two dimensional variation in stimuli have demonstrated increases in information transmitted varying from 2.3 bits for saltiness and sweetness combined (Beebe-Center, Rogers and O'Connell, 1955) to 4.4. bits for dots in a square (Klemmer & Frick, 1953). The addition of further variables increases the judgment capacity, but the additional information transmitted is less than additive (8).

While the findings reported here indicate that there is evidence of channel constraints at the level of primary reception of stimuli (the level of input transduction), it is not possible to go on to conclude that these limitations explain the organism channel capacity discussed earlier. While a particular cell or organ can be shown to have a limited judgmental capability, the total of all information provided by the sensorium as a whole far exceeds the amount which can be usefully employed by the organism. The retina of the eye alone contains in the order of one hundred million cells, and the optic channel to the brain carries about one hundred thousand nerve fibers. It has been estimated, for example, that the ear is able to transmit 8,000 bits per second, the

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(8) Both G.A. Miller (1956) and J.G. Miller (forthcoming) give a fuller report of the findings on which Lie conclusion is based.

eye perhaps 3.4 million bits per second (Jacobson, 1950, 1951). J.G. Miller has indicated that the channel capacity of the organism as a whole may be as low as 6 bits per second, and certainly not more than about 40 bits per second. The effective difference between the information provided to the brain, and the amount it is able to use clearly requires an explanation of a different order (9).

When in fact we turn from an examination of the information-transducing characteristics of the primary exteroceptor mechanisms to internal processes of organization, it becomes evident that much of the available sensory stimulation is immediately discorded. There appear to be internal filtering mechanisms which are utilized by the organism as a normal part of his perceptual process (10). Such mechanisms operate both within and between sensory modalities; the effect of the filtering is a reduced and more manageable picture of the environment, to which the organism can more capably respond. With respect to the two most important channels (for the human), the visual and the auditory, the process differs somewhat. The visual field normally contains a diversity of objects, to which we attend only in part. Everything which is going on in the field of view is not of equal importance, and we tend to

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(9) cf. the observation of Quastler and Wulff (1955): "It is fairly certain that the limitations of information processing are associated with the central part of the information-processing mechanism. None of the limitations observed could be ascribed to peripheral input mechanisms".

(10) As contrasted with the "adjustment" processes mentioned by J.G. Miller, this customary resort to omission, filtering and abstraction seems to form an essential element of the perceptual system. Even the phenomenon of information overload finds a useful application within the perceptual system as a whole: an example is "criterial flicker fusion", where the overloading of some cells permit certain specialized kinds of perception, necessary for example to film-viewing.

become conscious only of events which are relevant to our activities, so that other things in the periphery do not really exist for us. The eyes operate by making sequences of saccadic movements, or jumps from one fixation point to another, remaining fixated about 85 per cent of the time. In this way, if important events occur in different parts of the visual field, they can be scanned in a succession of fixations. Such scanning processes serve to permit the eye to select a point of attention and to ignore other information; they do not protect the individual from overload when the eye is simultaneously trying to keep track of more than one main information source. Mackworth and Mackworth (1956) projected up to 12 sources of information simultaneously subjects through separate windows. Decrements in performance as expected were associated with (1) the number of windows employed and (2) the amount of overlap of messages.

The ear works on another principle from the eye, and scanning is accordingly more difficult. Spatial relationship between events in the audioscope are difficult to determine with precision, while the perception of temporal relationships can be rather easily affected by overlap of messages, irrelevant atmospheric noise and the like.

If two messages arrive at once, and if both are relevant (to be attended to) the resulting overlap produced a considerable loss of information (Webster and Thompson, 1954; Poulton, 1956). Broadbent (1954) read lists of digits to subjects over separate channels into each ear.. Under conditions of overlap, subjects appeared to be able to deal with both sources at rather slow rates of presentation, but as the rate of presentation increased, they increasingly showed a tendency to pay attention to stimuli reaching only one ear. At certain speeds, he found that although inputs to one ear were dealt with before those to the other ear (the phenomenon of "prior entry"), subjects were able to retain additional information in memory for a relatively short period. These results, as noted earlier, depended on the amount of information associated with each message source: messages which convey little information can be dealt with simultaneously, while with more information overlap produces correspondingly greater decrements in transmission.

In general, if some information is to be retained, and some discorded, the ear is better able to select out the wanted portions of the message if the sources can be isolated, e.g., by being fed into different ears. Hirsh (1950) and Kock (1950) showed that noise has less effect on intelligibility if, for example, two loud speakers are employed separated physically, one for the relevant signal, the other for noise.

The findings reported here apply only to information-reduction processes within single sensory modalities; there are in addition losses due to interaction between multiple sensory inputs. In general, it appears to be possible to carry out simultaneously two redundant tasks involving more than one sensory modality: it is sometimes possible to drive a car and at the same time engage in animated discussion. This capability is in turn limited by the information-processing requirements of the separate tasks involved. However, when subjects are required to perform simultaneously visual and auditory scanning tasks, and if difficult material is presented to one channel and easy material to the other, the easy material is disregarded (Harris, 1950). When there is overlap involving symbolic material, presented rapidly, then one sensory input is disregarded completely (Mowbray, 1954). The presence of noise intensifies these effects (Broadbent, 1953).

Where the inputs arriving via different sensory channels are non-competing, there is some evidence of afferent stimulus interaction (Hull, 1952). The effects however are not necessarily additive; frequently it appears that where there is ambiguity in the interpretation of a stimulus receiver on one channel, the information provided by another sense is used as a means of verification (11). Thus there is a tendency for observers to interpret the directionality of sounds by means of an apparently related visual event (Thomas, 1941). When interpretations clash, it is the visual information which is given priority.

A general result in the experiments discussed here is that where there is competititon among signals, in the sense that alternate stimuli are present to be attended to, then the organism shows a tendency to suppress one source in the interest of continued successful reception of another source. There are two ways this can be explained. First, since the concept of suppression suggests a form of inhibition, we might suppose that peripheral sensory masking alone is sufficient to explain the difficulty of the organism in paying attention to two high-information sources. Broadbent (1958) rejected this interpretation in favor of a second explanation which supposes a rôle for mechanisms originating in

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(11) Birdwhistell(1970) has proposed that our use of non-verbal cues has a similar function in communication.

the central nervous system. The evidence for this conclusion comes from an examination of experimental eveidence concerning the effect of instructions on subsequent performance. When the subject is asked two questions simultaneously, if the experimenter announces which voice is to be answered, the subject is generally able to respond as instructed. In the absence of such instructions, or if the instruction is issued after presentation of the stimulus, the performance of the subject shows serious deterioration. Such results do not support a theory of peripheral sensory masking.

More recent results provide considerable support for Broadbent's point of view. Sperling (1960) and Neisser (1967) have produced experimental evidence which seems to be best explained by a theory of what Neisser terms transient iconic storage. When a visual stimulus is presented to a subject, the sensation of the stimulus may outlive the presentation of the stimulus. This is explained by the well-known psysiological finding that each sensory modality is associated with a projection area in the brain. The concept of an iconic memory supposes that "the persistence of visual impressions makes them briefly available for processing even after the stimulus has terminated" (Neiser, 1967).

The experimental method employed involves the use of tachistoscopic display of stimulus material. The principle of tachistoscopic experiments is that the subject is shown extremely brief presentations of material, which is then re-presented in successive exposures of gradually increasing duration. Sperling (1960) used rectangular arrays of letters such as

T D R

S R N

F Z R

which were displayed for periods of 50 milliseconds, too brief for the eye to respond actively by changes of fixation. In general, subjects were not able to read more than 4 or 5 letters (consistent with Miller's notion a "span of attention" or "span of apprehension"). Sperling then instructed subjects to read only a single row of the display. Subjects were cued by a different tone for each row, sounded after the tachistoscopic presentation. The result was near perfect accuracy for the selected row. Averbach and Coricell (1961) showed similar results, substituting a single letter for a row, and a visual pointer rather than a tone. Sperling's results have been replicated by Glucksberg (1965).

From these results, Neisser has concluded that a visual input can be stored briefly, that it decays rapidly, but that while still present in memory, information can be read from it. Subjects reported that the letters were visually present and legible, even though the stimulus had not any longer been present for 150 milliseconds.

A similar mechanism associated with auditory input has been posited by Neisser, who terms this auditory storage "echoic memory".

The significance of this theory, from the point of view of the present discussion, is that it leads us to the conclusion that the act of perception includes a process of "read-out" from the available ensemble of sensory stimuli, or a re-codification of input into another form which can be stored more easily. The translation of recoding must often imply going from a visual to a verbal medium. Neisser argues from this that "perception is not a passive taking-in of stimuli, but an active process of synthesizing or constructing a visual figure. Such a complex constructive act must take a certain amount of time" (Neisser, 1968). Such "analysis-by-synthesis" requires a concept of organization of activity based on what we termed early a contiguity relationship: a capacity to combine acts in sequence. Hence, included in the act of perception, is a performance which follows the type of organization we usually associate with motor activity. Perception includes an activity in which successive steps occur, and as Neisser notes, such an activity requires time to perform. But, as argued earlier, it is precisely output activities which are most affected by the rate of presentation of markers, independent of the rate of information transmission.

The rate of presentation of markers has two possible effects: (a) Since increases in rate of presentation necessarily must eventually reduce the duration of the stimulus, there must come a point where the brevity of display itself causes non-recognition. Mackworth (1963) showed that for values of less than 50 milliseconds, recognition declines sharply. (b) Increases in the rate of presentation of markers result in increased "crowding" of signals into a given temporal period. In this case, we should expect to find increasing confusion of one stimilus with the next, or "masking". There must in a word be a limit to the temporal resolving power of the visual system.

A great number of experiments indicate the correctness of this assumption; an interesting result associated with the theory of an iconic memory is the phenomenon of <u>backward</u> masking, in which a stimulus presented <u>later</u> masks or obscures an earlier one, which is still present as an icon (Sperling, 1960; Ekiksen & Lappin, 1964; Eriksen and Collins, 1964).

Within the analysis-by-synthesis model of perception, the role of attention is critical. Attention determines what region of the sensory field is to be read out, or re-coded (12). The processes of focal attention cannot operate on the whole field simultaneously. Such processes pre-suppose some degree of prior "setting": They can come into play only after preliminary operations have already segregated the figural units involved" (Neisser, 1967). Neisser terms such preliminary operations "preattentive processes". They "produce the objects which later mechanisms are to flesh out and interpret". They are identified with the performance of automatic motor responses. They are in essence crude, approximative images of the world, often as much determined by prior expectations as by the nature of the stimulus itself.

This has a clear implication for the situation where a rapid response is required. Fehrer and Raab (1962) measured latency of response to stimulus alone and stimulus followed by mask (where only an impression of movement was possible) and found no differences. Fehrer and Biederman (1962), Schiller and Smith (1966) obtained similar results. This finding illustrates the point that while, at one level, the process of read-out or recoding is still underway, the organism has already begun his response on the basis of a first signal that an event has occurred. "The mechanisms which register this onset are different, simpler, and faster than those which identify the letters" (Neisser, 1967).

This theory serves to explain two phenomenon alluded to earlier: (a) the association of error with increasing informational content of the message, and (b)Kornblum's (1967, 1968, 1969) finding that reaction

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(12) "A 'perceptual set' operates by affecting what the subject does during the brief period of iconic storage. This does not mean, however, that the set affects only "response" and not "perception"...There are no instantaneous perceptions, no unmediated glances into reality. The only way to use the term 'perception' sensibly is in relation to the extended processes that can go on as long as the icon continues". (Neisser, 1968)

times in sequences of equiprobable stimuli is significantly faster for repetitions than for non-repetitions (13). Error is naturally associated with increasing reliance on crude pre-attentive processes, while the "setting" of attention should be expected to follow the previous behavior, in the absence of other clues.

The distinction between pre-attentive processes and secondary recoding suggests in turn a reason for the relationship between information presented and latency of response. The concept of information is equivalent to that of variety, and is associated with the idea of "suprisingness". The image formed from the operation of pre-attentive processes is approximative and indistinct: it permits the organism to begin an (approximative) response while more refined verification procedures can be accomplished (and the response adjusted accordingly in the light of fuller information). The less informative the stimulus, it should follow, the more likely the image due to pre-attentive processes is to be accurate, and the more cursory can be the verification process. The more informative the stimulus, however, the greater the extent of verification required, and the slower the response. Such a theory accords well with Mowbray's conclusions on the effect of learning, since learning may be regarded as affecting both the automaticity of motor response and also the accuracy of pre-attentive

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(13) "These findings...suggest that the organism remains 'set' to transmit a signal like the one it has just processed more readily than other signals. In this it is like an elevator that remains at the floor at which it was last used rather than returning to the main floor". (Miller, forthcoming)

processes (14).

The Communication Model in Perspective

The late fifties, roughly the period when G.A. Miller's articles and Broadbent's book appeared, appear now to be the high-water mark of enthusiasm for information theory. There was more than a slight tendancy to state flatly that the human organism could be described as a communication channel. Even then there was an awareness of the limitations in the applicability of the communication channel model: as G.A. Miller (1956) observed ironically: "It is an act of charity to call man a channel at all. Compared to telephone or television channels, man is better characterized as a bottleneck". Subsequently, there has been if anything a further backing off from extreme positions on the subject. J.G. Miller, for example, appears to use the channel model more because it permits him to group together a variety of phenomena and hence to perceive certain general trends in a larger ensemble of research findings than would otherwise be possible; he is extremely careful to point out the limitations in the generality of the model. Such a use of models to provide a tool for empirically derived generalization is in the best tradition of science: one important criterion of any model is not so much whether it "explains" a phenomenon, as whether it works. Within limits, the communication channel model works, and its use is accordingly justified. Both on

(14) This line of argument appears compatible with the approach to signal detection utilizing statistical decision theory. See Swets, Tanner and Birdsall, 1964.

intuitive and on experimental grounds, it is correct to state a relationship between stimulus uncertainty and response latency (and ultimately efficiency of response).

Furthermore, these results are not limited to the somewhat unreal circumstances of the laboratory. Richard Meier has observed similar conditions in organizations which are subject to periodic overloading, such as libraries, stock market exchanges. Meier (1962) describes the eventual breakdown of information processing that occurred in the American Stock Exchange, in 1959, following a sudden quadrupling of orders. The relevance of this example to the information overload hypothesis has been pointed out more recently by J.G. Miller (forthcoming). The extent to which conditions of superabundance of available information and the resulting effects on habitants of the (increasingly wired) city has been discussed recently by Milgram (1970). We can hardly doubt therefore the validity of the overload hypothesis and its pertinence to the themes set out at the beginning of the report.

There are however difficulties. Laming (1968) has pointed out serious inconsistencies in the application of the Shannon model to choice reaction experiments. Shannon's concept of channel capacity was linked to that of coding. If the entropy of the source is less than or equal to the channel capacity of the transmitting system, then there must be a coding system which will permit transmission of the source message with an arbitrarily small error rate. To establish channel capacity, we would thus have to be assured that the original message had already been recoded in optimal form. But this in turn requires the examination of messages, if necessary, of infinite length, which in turn implies a (possibly infinite) coding delay. Clearly the analogy with most choice reaction experiments does not hold: whatever the reason for breakdown, or the confusional state, it can hardly be argued that the reason is that channel capacity has been exceeded, since the definition of capacity implies a condition of optimal coding, which cannot be shown to hold in the choice reaction experiment. Furthermore, Laming argues that the encoding system is embodied in the performence of the transmitter, which is to say the display system, and this is an invariant in the experiments we have been discussing, with the result that optimization of the transmission rate could not have occurred. Breakdown may be associated with varying levels of information, but cannot be a consequence of exceeding channel capacity. Hence the way in which Miller states his hypothesis (p. 17 of this report) is based on a misunderstanding.

"The simple manner in which Shannon's measure of entropy has usually been applied in psychology has already been criticized by Cronbach (1955). This measure applies only to ideal channels, in which messages are infinitely long, in which an infinite coding delay is acceptable (though not always necessary), and where complete and accurate knowledge of the probability structure of the signal series is stored in the system. In a choice-reaction experiment the messages are, of necessity, very short. The very design of the experiment requires that each signal must be passed completely through the system, encoded, transmitted and decoded and the response registered, before the next signal is emitted from the source. Reaction time must therefore include not only transmission times but also the time required to encode and decode the message and to execute the message" (Laming, 1968).

Evidence from at least one experiment (Kirchner, 1958), indicates under conditions of enforced delay of response, there is a decrement of performance, rather than an improvement as should be expected if in fact human beings could be compared to ideal communication channels, where there is a delay of more than three signals. Presumably other constraints become operative at this point, e.g., memory. Perhaps some remarks of G.A. Miller should have received more attention than they have: "The most glaring result(of the choice-reaction experiments) has been to highlight man's inadequacy as a communication channel... It is my own opinion that man's peculiar gift is his ability to discover new ways to transform, or to recode, the information which he receives. It seems to me that the very fact of our limited capacity for processing information has made it necessary for us to discover clever ways to abstract the essential features of our universe and to express these features in simple laws that we are capable of comprehending in a single act of thought. We are constantly taking information given in one form and translating it into alternative forms, searching for ways to map a strange, new phenomenon into simpler and more familiar ones. The search is something we call "thinking"; if we are successful, we call it 'understanding' " (Miller), 1956) (15).

Following Laming's argument, it would appear that the greatest value of the communication channel has been as a heuristic device, to lead to the posing of a number of useful questions. In the next section,

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(15) Although Miller himself in another article of the same year also used the term channel capacity in much the sense criticized by Laming.

however, we will attempt to show that the channel model, precisely because of its heuristic function, has tended to limit attention to a somewhat narrow class of phenomena. An attempt will then be made to develop an alternative approach.

SECTION III

A REVISED APPROACH TO THE OVERLOAD HYPOTHESIS

Limitations of the Concept of Transfer Function

Much of the literature of information overload has been couched, as we have seen, in terms of a model of the individual as a communication channel, which in input exhibits the irritability common to all living forms, but is otherwise the passive transmitting instrument of information-carrying events which impinge from the external environment. Its output reflects in appropriately transformed manner only these input events. Information overload in this perspective is uniquely a consequence of features of the stimulating properties of the environment (16). When overloaded, the organism adopts a strategy of defense, shutting off the information stream at its source, leaking it, filtering it, and so on. The"strategies" of defense are passive mechanisms and in no way affect the essential concept of the organism as a pipeline or channel between a given input stimulus and an output response, but a pipeline which carries information, rather than matter.

This model of the organism is exemplified in the concept of "transfer function". Experimentally realised, the transfer function implies the presentation of a stimulus (S) at time (t) and the observation of a response (R) at time (t+1). It is a transfer function if the response is a (perhaps non-linear) function of the stimulus, and of no other variable, i.e., $R\ t+1 = f\ (S\ t)$. In this section we will examine

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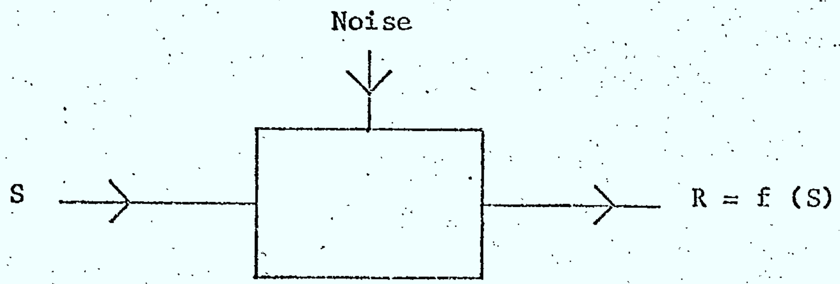
(16) cf. Lipowski (1971): "By attractive stimuli are meant those which arouse appetitive and approach tendencies in people on whom they impinge. Overload implies excees or surfeit of such stimuli, in that they exceed the individual's capacity to process, choose, approach and consummate".

the utility of the concept of transfer function, and, in so doing, provide the basis for a different approach to the modeling of organismic functioning and information overload.

Bair (1971) has recently distinguished three types of input-output function, which correspond to three models of information-processing machines. "The functions performed by man on received information may be divided neatly into three categories of tasks, information, conservation, reduction, and creation, which subsume more specific functions labelled transforms".

Information Conservation

In an information conservation model, not only is the output assumed to be a direct function of the input, i.e., $R_{t+1} = f(S_t)$ but also the function is assumed to be reversible. That is, given an output, and knowledge of the transformation performed by the organism, the original stimulus input could be determined. The machine which corresponds to this model is subject to two major difficulties: random error and dropouts (omissions, in Miller's terminology), both of which may be represented in information theoretic terms as noise. This model views man as essentially a re-coding machine, ultimately as a transducer. Graphically, the transfer function can be represented in the following way:



Experimental conditions which exemplify the information conservation task are described by J.G. Miller (1962):

> "To test our individual subjects, we designed and built an Information Overload Testing Aid apparatus, which we refer to as an 'IOTA'. This is arranged to present stimuli to the subject on a ground-glass screen which is on a table in front of him. He responds by pushing the proper buttons. Stimuli are thrown on the back of a screen by a projector, a perceptoscope, which shows movie film at rates of from one to 24 frames per second. Our film presents black arrows on a white background, appearing in from one to eight of the eight two-inch vertical slate which run down the screen. There are 8 possible angular positions, like those of clock hands, which the arrows can assume. There are 8 corresponding buttons for each of the buttons being used... If an arrow in Position b appears in Slot 3, the only correct response is to push Button b of the set for Slot 3".

The transfer function, in the literature on information overload, is effectively the <u>criterion</u> function, since less than complete conservation of information is regarded as unsuccessful response: the next class of functions to be discussed tends to be regarded as "defenses" adopted by the individual in the face of overstimulation.

<u>Information Reduction</u>

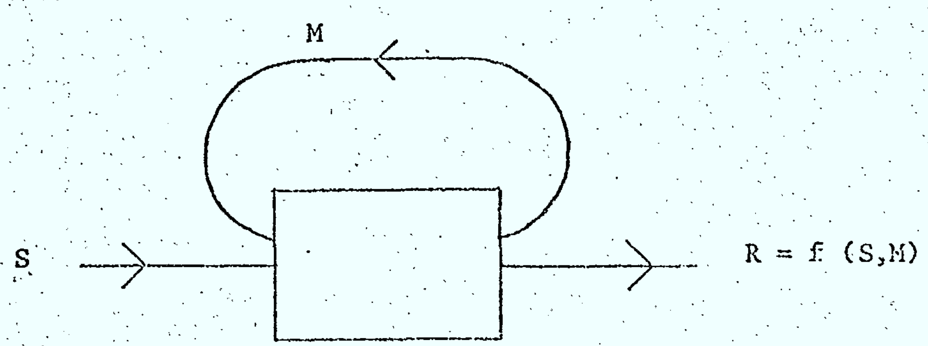
Information reduction machines produce a systematic loss of information, while at the same time maintaining essential features of the input. The associated functions are thus not in general reversible. Reduction models may be further classified according to the type of reduction involved:

i) Filtering

The concept of filtering is that some types of input are systematically given higher priority than others, or that some inputs are consistently screened out, ignored, lost.

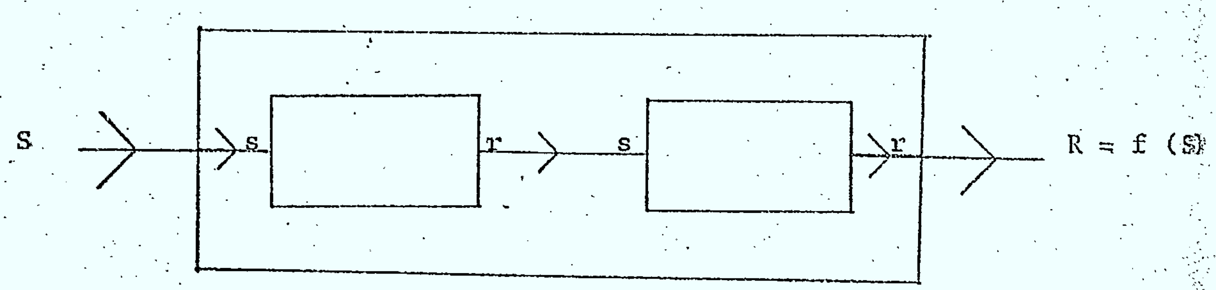
ii) Condensation (Abstraction)

In condensation, none of the input information is ignored, as is the case for filtering. Rather the signal is processed to produce an output which represents in reduced form the input. Arithmetical operations such as addition, substraction, multiplication, division, are examples of condensation. Machines capable of condensing information require a memory capacity. First, the machine must store an algorithm or program which is capable of providing instructions concerning the steps involved in the reduction. Secondly, the input information constitutes data which frequently must be held in short term storage while awaiting processing. Graphically, we represent memory capacity by a self-terminating loop, as follows:



iii) Contingent transformation. (Sequential Processing)

The concept of contingent, or sequential, processing of information is similar to that of condensation; however, in contingent processing, it is further required that the output of one program serve as the input of a second. The relevance of this model for human concept formation has been discussed by Hunt (1962) and Biederman (1966). In addition to memory, such a machine includes a selector, or executive, component, which guarantees that the operations or subroutines are performed in the appropriate order. The analogy of a computer program has been widely employed to illuminate the processes involved in contingent transformation of information. Graphically, such multi-staged algorithmic transformations are represented as programs with programs contained within them:



Information Creation

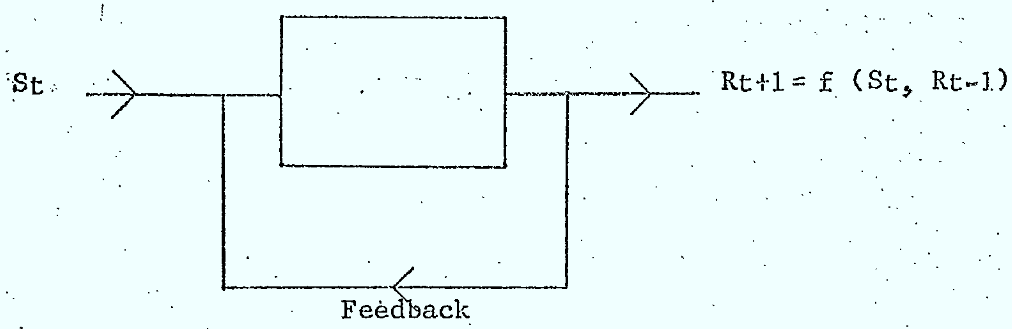
Bair (1971) discusses a transformation which he relates to information creation tasks and which he refers to as a "one to many mapping of stimuli resulting in a greater output than input". The sense in which he employs the term "mapping" is evidently not the same as its conventional use in mathematics. A one-to-many "mapping" implies the existence of further unspecified variables. From Bair's discussion, it appears that two fundamentally different models are involved:

i) Information retrieval

The example given by Bair is the task of multiple word association, in which one stimulus word produces a chain of output responses. To explain this phenomenon, we require, in addition to the notion of a program, a long-term memory. Within the memory, data in the form or words are organized by a principle of association, so that the stimulus word serves as an entry point to the list. The output is then dictated by the program instructions (presumably including a "stop" rule), and by the organization of the stored list of words. The output is therefore no longer a function only of the input, but also of memory. Since memory in turn implies a previous process of learning, the new output is in effect a function of the present input, previous inputs, and (for reasons explained in the next section), previous outputs. This cannot be considered a "transfer" function.

ii) Match-mismatch feedback

In a probabilistic learning task, the subject is required to decide for each trial in a continuous sequence of trials which of a set of events will occur. If the subject receives knowledge of the results (KR), he will tend to use this information, which provides him with clues about the probabilities of the events, in order to guide his subsequent choice behavior. (Hilgard and Bower, 1966; Schipper, 1967; Posner, 1965). (i) and (ii) above differ principally in the memory requirements, and the immediate role of feedback in the process. Graphically:



This discussion reveals a fundamental difficulty inherent in much of the discussion on information overload. Whether one likes or dislikes the term "information creation" as a label for information retrieval and feedback, it is apparent that memory and learning are very nearly universal elements of human behavior, and a theory which is restricted to explaining behavior in which these fundamental processes are absent, is excessively limited in its application. Yet, as we saw earlier, the main hypotheses of information overload have pre-supposed that behavior could be viewed within the frame of reference of a transfer function. We have seen that this assumption fails to hold for information creation tasks. In these latter instances, since the output is a function of variables other than the immediate input, the range of variation of information content of the stimulus input should be found to have less importance in determining the output, and this is in fact what Bair concludes from his (admittedly cursory) review of the literature:

> "The generalization that task difficulty increases with increasing transmitted information has been shown to be not entirely applicable to information creation tasks. In information creation tasks, reaction time is more closely correlated with response uncertainty (variance) rather than transmitted information". (Bair, 1971)

The difficulty appears to be twofold: (a) insufficient attention has been paid to the <u>function</u> of stimuli for the organism, and (b) sources of information have been too narrowly defined with respect to the organism.

The notion of the human as an information channel seems to have blinded workers to the purposive aspects of behavior: for the most part, organisms do not passively receive stimuli; rather they actively seek out sensory information. The connotation of the word stimulus itself suggests this.

The point can be illustrated by reference to a simple example drawn from everyday experience. We can imagine a man walking down a long flight of stairs. For part of the way, the steps are quite broad, so that the walker has to take two steps to cross each step and one pace down to the next. At a certain point the stairs curve to the right, then straighten out, but at this point they become narrower, while the "lift" between each becomes higher. Eventually the walker reaches the street and turns left.

Suppose the man is buried in thought, so that most of the task occurs "automatically". If the steps are long, the walker quickly falls into a rhythm of two across and one down. The only information he now needs is a stimulus which indicates that he has to change from a two-and-one straight-down program to a two-and-one right-turning to a one-and-one straight down to a flat-surface left-turning to a flat-surface straight-ahead program. How are we to evaluate stimulus input information in this case? It would seem most useful to perceive visual information as constituting signals by which the full complex program is organized. Any explanation which emphasizes that the individual appears on observation to actively organize his head movements in order to "scan" his environment for the needed cues to change his behavior and hence suggests selective attention and information-seeking behavior is likely to be a more adequate explanation than one which begins by a description of the uncertainty in the environment. We could imagine of course that the set of stairs is a stimulus presented to the walker and his walking is merely the appropriate response (there are in fact certain advantages in conceptualizing it in this way), but in order to do so we should have to take account of the role of purpose in the resulting "experiment." There is no outside experimenter to set the criteria for successful performance of the experience; it is the walker's own objectives which establish the order of presentation of stimuli.

A re-examination of the experiments of information overload in the light of this discussion leads to the abandonment of a theory of "transfer function", and in turn to the abandonment of the communication channel concept. What the experiments using reaction time as a criterion effectively demonstrate is essentially that a person can only run so fast down a set of unfamiliar steps in the fog. A fuller account of information overload, in our view, must take into account in addition the purposes of the individual, the programs he is executing, the importance of feedback and the role of perception in providing appropriate signals for the carrying out of his programs.

There is, as suggested earlier, a second difficulty related to the definition of environment (and hence source of stimulation) generally employed. The experimenter has generally been able to manipulate the conditions of the external environment. It tends to be overlooked however that there is a second environment, the internal environment. (Deese, 1967, p. 47; Miller, Ratliff and Hartline, 1961). Such internal environments have recently been shown to be in turn subject to experimental manipulation (Schacter, 1964). By the internal environment is meant the functioning of the organism itself, and the numerous internal processes by which the individual accomplishes homeostasis. The same information processing system which receives information concerning external events also receives messages from the internal environment. These latter messages serve in a certain way as an index of our success in responding to changes in the external world.

In this context, we may view the individual as being the recipient of two orders of feedback, one direct, one mediated by the dependence of the states of the internal environment on those of the external environment.

The conclusion to be drawn from this is that we may not safely in all cases ignore the effect of variables other than those of the immediate stimulus configuration when evaluating the effects of rates of information on the performance of the individual. We must thus be sure how the subjects situates the stimulus within his image of the world.

Plans and behavior

At this point we will attempt to outline a somewhat different approach from that exemplified by J. G. Miller and others. In this revised perspective, the role of plans in behavior will take on a greater importance. We will in fact hypothesize that the confusional state occurs when the organism is unable to complete a plan or program. We will then want to inquire how different conditions of information availability affect the carrying out of plans.The overload hypothesis will then be re-stated.

Rather than visualize the organism as a channel for the transmission of information, we conceive him as exhibiting behavior which is guided or produced by a program, consisting perhaps of a collection of subroutines, which are stored, which can be occasionally modified and supplemented, and which are available to be called up by appropriate instruction from the main program. Such subroutines are in fact conceived as being triggered by specific stimuli.

Such a model of behavior has been shown to fit a variety of patterns of behavior observed among organisms less developed than man.

The larvae of barnacles will swim upwards towards the surface or downwards towards the bottom of the sea depending on the relative warmth or cold. This program could be represented as the following:

```
     SUBROUTINE DEPTH;
     IF TEMP >  K + A  THEN CALL SUBROUTINE SWIMDOWN;
ELSE IF TEMP <  K - A  THEN CALL SUBROUTINE SWIMUP;
     RETURN
     STOP
```

Additional examples can easily be added: Ethologists have for example made detailed analyses of the behavior of the small fish called the stickleback which show that explicit cues are required in order to set into motion an entire sequence of behavior. There is a term for such stimuli: "releasers".

The notion which is employed by J.G. Miller of the organism as a set of subsystems through which information is relayed is not dissimilar to that of the reflex arc: stimulus → receptor → afferent nerve → connective fibers → efferent nerve → effector → response.[18] The concept of information processor as a collection of subroutines organised by an executive routine is of a decidedly different order:

> The neural mechanism involved in reflex action cannot be diagrammed as a simple reflex arc or even as a chain of stimulus-response connections.

18) Cf. Miller (1962) Where he identifies the following set of subsystems: Boundary → input transducer → internal transducer → channels and nets → decoder → learner → memory → decider → encoder → motor or output transducer.

> A much more complex kind of monitoring, or testing, is involved in reflex action than the classical reflex arc makes any provision for. The only conditions imposed upon the stimulus by the classical chain of elements are the criteria implicit in the thresholds of each element; if the distal stimulus is strong enough to surmount the thresholds all along the arc, then the response must occur... The threshold, however, is only one of many different ways that the input can be tested. Moreover, the response of the effector depends upon the outcome of the test and is most conveniently conceived as an effort to modify the outcome of the test. The action is initiated by an "incongruity" between the state of the organism and the state that is being tested for, and the action persists until the incongruity (i.e., the proximal stimulus) is removed. The general pattern of reflex action, therefore, is to test the input energies against some criteria established in the organism, to respond if the result of the test is to show an incongruity, and to continue to respond until the incongruity vanishes, at which time the reflex is terminated ... Consequently the traditional concepts of stimulus and response must be redefined and reinterpreted to suit their new concept. Stimulus and response must be seen as phases of the organized, coordinated act ... Because stimulus and response are correlative and contemporaneous, the stimulus processes must be thought of not as preceding the response but rather guiding it to a successful elimination of the incongruity. That is to say, stimulus and response must be considered as aspects of a feedback loop.
>
> Miller, Galanter and Pribram (1960)

The organism, in such a model, is conceived to be continuously directed by a program in which control passes from one subroutine to another, and one from stage to stage within the subroutine. The organisms performs operations (output) and makes tests (input). It utilizes sensory data in order to accomplish certain outcomes; it is stretching a point to consider this as the transmission of information in the sense of a channel, although acting like a channel is one possible task which the organism can undertake.

The efferent control of sensory input

The real disadvantage of a communication or transfer function model is that it takes insufficent account of the fact that man is a general purpose machine, capable of performing many kinds of activity in a variety of environments (including, when called upon, acting as a subject in a choice reaction experiment). If man is merely a signal transmision system, then he is activated when signals are presented to him. His behavior depends on the nature of the stimulus field in which he finds himself; we would not suppose him to look for stimulation. The advantage of a "program" model is that it lends itself to the explanation of adaptive behavior. However, it also implies some re-orientation of perspective with respect to the inputting of information. This topic is considered in this section.

If the assumption is made that all behavior is guided by a program, or plan, than it should follow that there is a set of choice points, where the presence or absence of a certain indicator determines the choice of the next sequence of behavior. The thesis of central direction of behavior, when contrasted with that of man as a communication channel, requires a different interpretation of the choice reaction experiment. In the latter, the subject faces a display panel on which an event is to occur (perhaps the appearance of a light, varying, let us say from red to yellow to green) and a control panel with parts he is required to operate (suppose three buttons worked "R", "Y" and "G"). He is informed that each button matches up with a single light, and that any time a light appears, he must hit the correct button, in the shortest possible time. Other possible stimuli are now irrelevant to the assigned program: the sound of a distant siren, the color of the experimenter's tie, the clock on the wall. Attention becomes riveted on the display panel, and the motor mechanism is arranged for optimal response. The accomplishment of the task (or completion of the program) requires information. When a light flashes on, the test is performed: "Red? Yellow? Green?" and depending on the result execution follows. After verification to determine that the program has in fact been completed, control passes back to stage one, ready for the next run of the program.

The concept of stimulus is defined by the functional role of information within the program: it is not objectively determinable by reference to external criteria. The experimenter is reduced to infering the nature of the stimulus from his observations of events in the environment of the organism and the organism's subsequent behavior; whatever stimulation is <u>potentially</u> available, the "stimulus" is what the organism responds to.

From this we should be led to suspect that stimulus input mechanisms, like motor output, are subject to central control. What evidence is there for this assumption?

In addition to the evidence presented earlier in the discussion of iconic memory and pre-attentive processes, come physiological evidence can be adduced which supports the theory of a measure of efferent control over input. Jung, Creutzfeldt, and Grüsser (1957), Creútzfeldt and Grüsser (1959), Jung (1958) have demonstrated that stimulation of the thalamic region of the brain stem may alter the critical flicker fusion of cortical neurones. The nonspecific thalamic nuclei and the reticular formation are usually considered to be the mechanisms which control arousal and attention (French, 1957) and are the most likely candidates for the role of the control mechanism which was hypothesized in the preceding discussion (Wooldridge, 1963). French (1957) performed an experiment which demonstrated the control of reflex motor reactions by the reticular formation. The degree of a response of an anesthetized monkey to knee taps was recorded: it was shown that activation of the reticular formation affected the intensity of the response. French was led to conclude from a review of the evidence that "these centers can enhance or inhibit sensory as well as motor impulses. In short, the RAS acts as a kind of traffic control center, facilitating or inhibiting the flow of signals in the nervous system."

"The astonishing generality of the RAS gives us a new outlook on the nervous system. Neurologists have tended to think of the nervous system as a collection of more or less separate circuits, each doing a particular job. It now appears that the system is much more closely integrated than had been thought. This should hardly surprise us. A simple organism such as the amoeba reacts with totality toward stimuli: the whole cell is occupied in the act of finding, engulfing and digesting food. Man, even with his 10 bilion nerve cells, is not radically different. He must focus his sensory and motor systems on the problem in hand, and for this he obviously must be equipped with some integrating machine.

"The RAS seems to be such a machine. It awakens the brain to consciousness and keeps it alert; it directs the traffic of messages in the nervous system; it monitors the myriads of stimuli that beat upon our senses, accepting what we need to perceive and rejecting what is irrelevant; it tempers and refines our muscular activity and bodily movements. We can go even further and say that it contributes in an important way to the highest mental processes - the focusing of attention, introspection and doubtless all forms of reasoning".

Granit (1955) found evidence that activation of the reticular formation was capable of causing potentiation or inhibition of photocally induced activity in retinal cells, indicating centrifugal effects. Hernández-Peón, Scherrer and Velasco (1956), in a famous experiment, determined that activation of the brain stem area was able to depress afferent conduction at the lateral geniculate body in the visual pathways, and hence to produce a reduction in sensory impulses to the visual cortical receiving area. Their findings indicated that the effect was due to a true inhibitory influence from the brain stem reticular formation. This influence was modality-specific. They concluded: "It appears that this effect is exerted by inhibitory centrifugal fibers to the retina, and that their functional role, therefore, is to block sensory impulses during attention, preventing them from entering the brain, and from interfering with the neural mechanism of integration occurring during that physiological situation."

While these experiments support a theory based on the concept of a central control mechanism which directs the attention of the organism, selects response programs, and supervises stimulus input, it does not state on what basics reticular activation is brought into play, or how perception occurs.

Pre-attentive processes

Neisser, it was seen earlier, proposes a two-step model of perception: in a first step, the organism was alerted and a rough general picture formed; in a second, the information was read out in greater detail. Sokolov (1960) has discussed in some detail the experimental evidence for the mechanism termed by Pavlov an "orienting reflex". This reflex is non-specific; it occurs as a result of any increase, decrease, or qualitative change of a stimulus; and it produces as well a primary non-specific response. The orienting reflex "is evoked when the neuronal model set up in the brain does not coincide with all the parameters of the stimulus." The stimulus might be a sound, cold, a shock: "The orienting reflex is produced not only by the stimulation itself, but by impulses arising as a result of non coincidence between a certain cortical pattern (the model) and the applied stimulation."

In addition to the generalized orienting reflex, Sokolov identifies a localized orienting reflex, which is modality-specific. The function of this mechanism is to increase the discrimination power of analysers, as a result of direct stimulation through descending pathways to receptors from the reticular formation and the cortex.

A theory having similar elements to that of Sokolov has been advanced by Melzack and Wall (1965) to explain the findings concerning the experience of the sensation of pain. While the full details of their theory are not relevant here, the following conclusion is pertinent: "It is now firmly established that stimulation of the brain activates descending efferent fibers which can influence afferent conduction at the earliest synaptic levels of the somesthetic system. Thus it is possible for central nervous system activities subserving attention, emotion, and memories of prior experience to exert control over the sensory input. There is evidence to suggest that these central influences are mediated through a gate control system.[19]

"The manner in which the appropriate central activities are triggered into action presents a problem. While some central activities, such as anxiety or excitement, may open or close the gate for all inputs at any site on the body, others obviously involve selective, localized gate activity. Men wounded in battle may feel little pain from the wound but may complain bitterly about an inept vein puncture ... The signals, then, must be identified, evaluated in terms of prior conditioning, localized, and inhibited

19) The authors propose a model of such a system based on rather complex feedback mechanisms.

before the action system is activated. We propose, therefore, that here exists in the nervous system a mechanism, which we call the central trigger, that activates the particular, selective brain processes that exert control over the sensory input."

The authors than note that certain pathways projecting in the brain stem and thalamus are extremely fast, and that message arriving on these pathways could activate selective brain processes to receive subsequent afferent valleys arriving over more slowly conductive fibers.

Each of these theories are built around the role of match-mismatch error signals indicating variety in the environment which must be attended to. We must now explain how the subsequent information is analyzed.

Perceptual analysers

> Perception is not determined simply by the stimulus patterns; rather is a dynamic searching for the best interpretation of the available data ... It seems clear that perception involves going beyond the immediately given data of the senses; this evidence is assessed on many grounds and generally we make the best bet, and see things more or less correctly. But the senses do not give us a picture of the world directly; rather they provide evidence for checking hypotheses about what lies before us. Indeed, we may say that a perceived object is a hypothesis, suggested and tested by sensory data.
>
> Gregory, 1966

The process of perception will be illustrated here only with respect to the visual channel. While the detailed processes of perception are very different for other channels, we assume here that at higher levels, much the same principles apply.

The retina is composed of rods and cones, the rods being connected in large groups to secondary nerve fiber conductors, the cones being connected to fewer individual nerve fibers. The experiments of Hubel and Wiesel (1962) conclusively demonstrated that the retina functions essentially as a pattern recognizing device. Single cells in the visual area of a cat's brain proved to respond only to certain patterns of stimulus on the retina. A bar of light would stimulate a given cell only when presented at a certain angle; for other angles the cell remained silent. Different cells respond to different angles. The general principle which these results illustrate had been stated as early as 1942 by Lashley: "The principle involved is that the reaction is determined by relations subsisting within the stimulus complex and not by association of a reaction with any definite group of receptor cells." This accounts for the fact that we see the same object even though its image happens to fall on a different part of the retina.

Cells which are deeper in the brain intern respond only to more generalised characteristics. (Hubel and Wiesel, 1962). We are led to view perception, from this evidence, as a process of identification of dimensions of stimuli, of increasing generality as higher order mental processes are involved, and information is integrated from additional sensory channels. Visual impressions, finally, "consist of organized objects, seen against a less coherent background. Discriminative reactions, when analyzed, are found to be based upon certain generalized features of the stimulus." (Lashley, 1942).

The primary task of perception in this view is identification and classification. This suggests an explanation for our earlier observation that although the senses provide on overwhelming ensemble of information, the organism as a whole seems to transmit little. The point is made by Morrell (1967): " ... Information is processed in parallel in thousands of cells so that the organism need not depend on the reliability of any single element for identification of an experience. These parallel chains need not all carry exactly the same information and, strictly speaking, therefore may not necessarily be redundant. It is only necessary that the nervous system receive enough information about an experience to identify it even if some aspects are left out or distorted. Furthermore, it is likely that on first exposure to a stimulus, the nervous system specifies it less precisely than after many exposures. Ultimately, the code must be transformed from one based upon a discharge pattern through time to one that is more stable, i.e. immune to electrical interference, more disseminated, and susceptible of very much faster read-out."

The point we are making is nowhere better illustrated than by reference to the classical question of why the world remains apparently stable when we move our eyes - why we do not experience the "swish-pan" effect of a film or television camera system which also depends on an optic system similar in some ways to that of the eye. Evidence now appears to clearly support an outflow theory of Helmholtz, which states that command signals flowing outward to the eye/head effector system are monitored by an internal loop in the brain and fed into the analysis process in order to correct for head movements and thus retain stability of image. (Gregory, 1966). This phenomenon seems rather convincing evidence for the rejection of a simple transfer function theory of information processing.

The importance of active analyzing processes becomes even more salient when we turn to the question of recoding of perceptual information into symbolic forms.

Symbolic representation of stimuli

We have proposed that the process of perception includes a recoding, or "read-out,", component; the necessity to suppose the existence of a read-out mechanism becomes peculiarly evident when we turn to the question of how perceptual data gets to be represented in symbolic (above all, linguistic) form. The simplest explanation - that each symbol of the language becomes, through conditioning, associated with certain stimuli and thereafter functions as a sign of the original significate - was effectively shown to be in certain respects grossly inadequate by Chomsky in his 1957 review of Skinner's Verbal Behavior. The theoretical difficulty is that the grammar of a natural language is capable of generating on infinite number of syntactically well-formed sentences, and indeed in ordinary discourse "new" sentences are constantly being produced. If meaning were the result only of conditioning, we ought to experience great difficulty in understanding new sentences. The fact is however that we are presented with novel sentence often, and may have no trouble in comprehending them. Furthermore, the process of human thinking, by universal experience, involves the manipulation of symbols, to arrive at conclusions which are not derived directly from empirical evidence, although they may subsequently be so tested. S - R theories of language provide relatively poor explanations for such a process.

A "read-out" model assumes that incoming sensory data are recognized as comprising one or another pertinent pattern. Thinking about the world requires first that sensory impressions be mapped onto symbolic forms or images, such that, ideally, a one-one correspondance can be supposed to hold between the symbolic image of the world and the world itself. All inputs originating as non-symbolic events may be thought of as transformable into symbolic equivalents. If the image, or symbolic model of the world, is explicitly linguistic, then it consists of an ensemble of sentences.

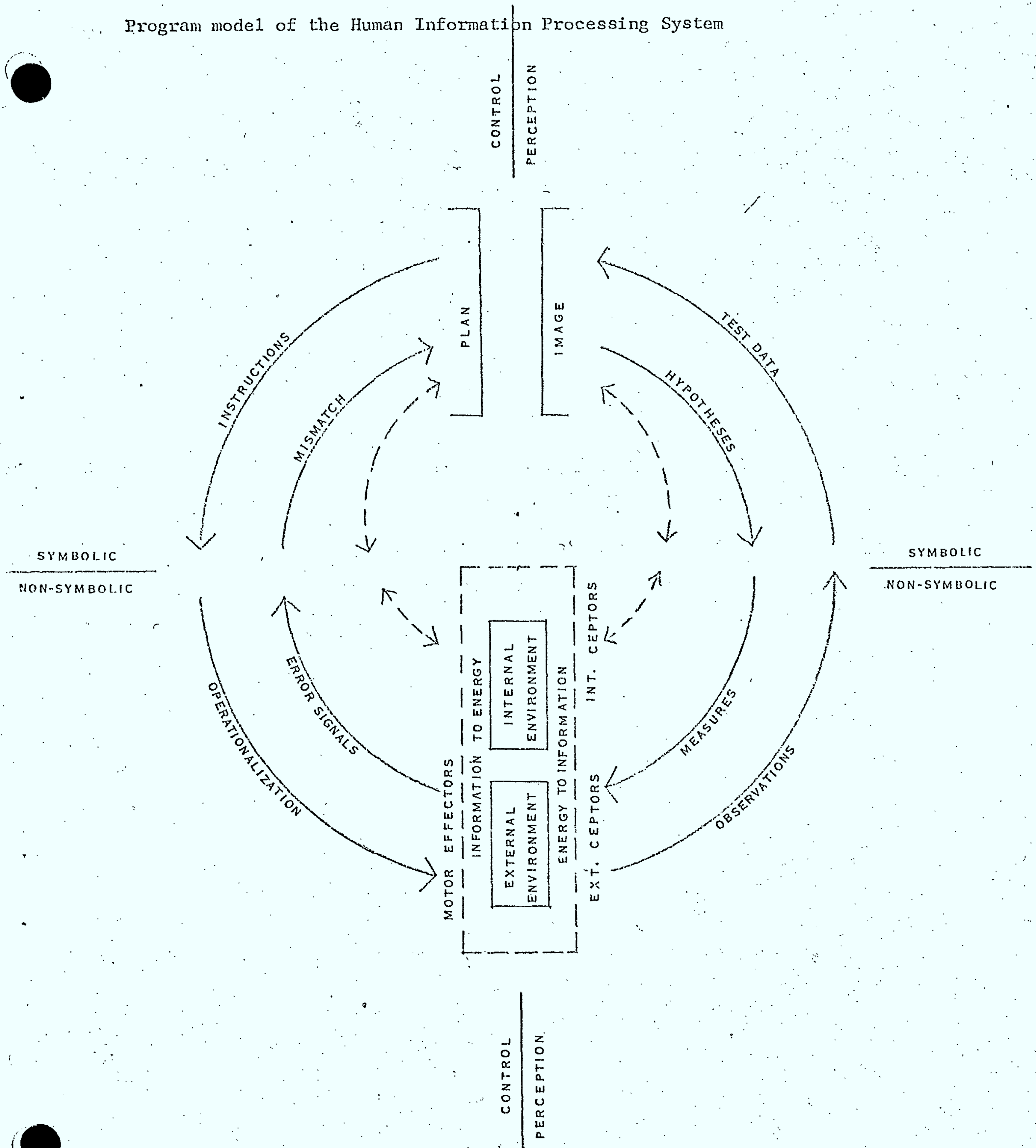
The problem which the individual faces is to keep his model up to date. How is this accomplished? First, we assume that he receives indication of a mismatch between his existing image and the real state of the world (perhaps via the orienting reflex discussed earlier). To alter the model, a new sentence, or sentences, must be generated. These may in turn be verified by comparing them with available sensory information. We should have to suppose that sentences are generated sequentially, tested, and depending on the sign of the test, either the model is adapted, new sentences are generated and/or additional sensory information is sought. Another way to express this process is to describe it as hypothesis - testing. Since the number of possible sentences is infinite, the process is in principle nonterminal. Presumably however other mechanisms come into play to limit the process.

How are hypotheses confirmed and disconfirmed? The sentence which is generated will have two logically distinct components: a referent or referents and a predicate which attributes something about the referent (s) or states a relationship between referents. The referent may be an explicit object (s) or a class (es) of objects. In the sentence "That rose is red", the referent is "that rose" and the predicate is "red". In order to verify such a statement, two steps are required: first, a set of measures will have to be decided on _a priori_ for the concepts _rose_ and _red_. In their simplest form, such measures are simply categories; in other cases, a scale may be implicated. The consequence for the organism is that before encountering sensory stimuli, he has available a set of classes into which we can order observations. Such an assumption is consistent with physiological evidence indicating that brain analyzers are activated _before_ other stimuli appear. Second, upon encountering sensory impressions, a decision must then be made concerning how to class the sensory impressions. Objects are discriminated. There are thus two phases: _application of measures_ and _classification of observations_.

When the measuring and classifying task has been completed, one further step remains, to compare the data against the original hypothesis: the

Figure 3

Program model of the Human Information Processing System



observations obtained are not data until they are made to serve the function of mismatch or error signals (in the sense of hypothesis-confirmation and -disconfirmation). The complete process from hypothesis generation to data analysis is regarded as a feedforward process: perception, in this model, consists not of passive reception of stimuli, but active obtaining of feedback signals serving to modify a pre-existing image.

This approach assumes that perception resembles motor activity, with the difference that to effect motor events, instructions rather than hypotheses are generated ("Cut the red rose" rather that "That is a red rose"). The instructions are broken down into separate actions,the changes of state in the effectors are signaled by means of proprioceptive channels and evaluated as mismatch or error signals. The process is illustrated in Figure 3.

Feedback and Information

Within the approach outlined above, the role of feedback has been given a central place; it is seen to be essential to perception, to the effecting of motor activity, and to the control of behavior itself. At this point, it is pertinent to enquire what revisions in our conceptualization of information are required within this altered perspective.

The subject in a task situation is in a state of uncertainty, first as to the nature of the stimulus which is to be presented to him, secondly as to the nature of his response, thirdly as to whether his response was "correct", in the sense that it reduced mismatch signals to within acceptable limits. In the latter case, the task has been accomplished.

It was seen earlier that the amount of information contained in the input signal is identical with the reduction of uncertainty (and hence depends on the ensemble from which the input signal was drawn). Feedback provides knowledge of the results (KR) of his response. It reduces uncertainty concerning the outcome of his response. The information value of the KR, or feedback, depends on the number of kinds of KR which could have been sent to the subject, i.e. on the variety in the KR message ensemble.

We may define two types of KR: (a) intrinsic KR, which is feedback that is either the result of propricceptively available information (muscle stretch cues are an example), or is usually present to the individual in the performance of a particular task (as for example in steering tasks, where visual information can be used to supplement kinesthetic cues); and (b) extrinsic, or augmented, KR, which is present only when an additional feedback loop to those usually present is found. This latter type of KR is peculiarly susceptible to experimenter manipulation: it may in many cases simply consist of the experimenter (or his stooge) informing the subject how he has done. Augmented KR provides a means to "train" a subject to perform a task according to certain criteria: the subject should be expected to continue to modify his behavior until he has eliminated or reduced the mismatch signals - in this sense the application of extrinsic KR is equivalent to that of a reinforcement schedule.

This distinction permits a further. We may discriminate between two types of experiment, according to the role played in each by augmented KR: (a) skilled performance, and (b) concept formation experiments.

In skilled performance experiments, the criterion for satisfactory performance of the experimental task is unambiguous. In an experiment of Trowbridge and Cason (1932), four groups of subjects were required to draw

100 lines all of a specified length. After each attempt, the experimenter provided augmented KR, of three kinds: (1) spoken nonsense syllables, (2) right/wrong messages, and (3) magnitude of error messages. In the control condition, no KR was provided. The results indicated the importance of information to the subjects: in condition (1) and the control condition, there was no improvement of performance; in conditions (2) and (3) improvement occurred, with maximum learning in the case of (3).

Skilled performance experiments are not limited to motor adaptation problems; there are also perceptual skills such as detection, monitoring (vigilance), discrimination, judgment, identification and recognition. In a series of experiments, Swets (1962), Swets, Harris and Rudloe (1964) presented subjects with complex sound signals, permitted to take any of five values on five separate dimensions. The subject's task was to learn to distinguish between each tone; they were given options as to how they would receive KR: e.g.,

(1) <u>prompting mode</u> - typed answer followed by correct tone then stimulus tone

(2) <u>test mode</u> - tone followed by typed answer plus more detailed information along the range of five dimensions

(3) <u>repetition</u> - the computer repeated the tone or played-back tone corresponding to the subject's wrong answer

It was concluded that

(a) subjects engaged in a great deal of inefficient experimentation, spending varying amounts of time in different modes exploring various ways of receiving KR (mode 1 was most efficient);

(b) an important effect of KR is to increase the S'S readiness to respond rather than to increase sensitivity to the signal as such.

The choice reaction experiments to which the hypothesis of information overload has been most frequently related are based upon, for the most part, skilled performance tasks. The effects of augmented feedback do not in these researches appear to have received a great deal of attention. The application of extrinsic feedback by the experimenter, in order to "teach" the subject a standard of performance, violates the concept of a transfer function. The subject must learn to discriminate the appropriate stimuli, understand which response can be acceptably associated with each stimulus, and finally learn to perform the correct response. In concept formation experiments the learning of the rules governing the appropriate correlation between stimulus and response are made much more complex. With respect to this type of experiment, it will be seen, it is more appropriate to ask how much information is used, or must be used, to complete a single correct response.

Hypothesis testing and the formation of concepts

> "One might speculate that, in the adult human subject, any task that leads to the search for a rule, for example one that relates the subject's response and the experimenter's 'reinforcement' must first produce the specification of the rule before the rule can be applied... There is now adequate evidence that the adult human organism will usually generate rules or hypotheses whenever the environment demands some consistency in behavior".
>
> Mandler, 1964

> "The number of ways in which an array of events can be differentiated into classes will vary with the ability of an organism to abstract features which some of the events share and others do not ... Categorization at the perceptual level consists of the process of identification, literally/an act of placing a stimulus input by virtue of its defining attributes into a certain class ... By categorizing as equivalent discriminably different things, the organism reduces the complexity of its environment ... To know by virtue of discriminable defining attributes and without need for further direct test ... is to know in advance about appropriate and inappropriate actions to be taken.
>
> Bruner *et al.* 1956

Experiments in concept-learning are concerned with human being's use of information to learn or recognize "patterns." In a series of experiments conducted during the fifties, Bruner, Goodnow and Austin (1956) investigated some of the conditions under which subjects were able to attain new concepts. In a concept attainment experiment, the subject is required to discover a principle of grouping stimuli into equivalence classes: he must determine the intrinsic attribute properties which serve to characterize members of a given class. Experimentally two main elements are required for the performance of the task: a) a sequence of *instances*, consisting of pictures of objects, geometric patterns or even words, each instance being characterized by a set of attributes - - geometrical figures varying in size, shape, color, number, orientation, etc, which in another experimental situation would be simply referred to as stimuli. Subjects are then required to produce a single response to a stimulus set according to the desired attribute dimensions. (For example, "sort instances of all red forms regardless of shapes as opposed to other-colored forms."). b) The second element consists of knowledge of the results of his attempts at identification (KR), or validation, for each presentation of an instance. The subject must be able to assume an underlying pattern in the sample of stimuli presented to him, and accurate feedback on the results of his guesses. Each attempt at identification followed by validation provides the subject with information, since it constitutes a test which limits the number of attributes the subject has to take into account in attaining the concept.

There are two main types of concept formation experiment, depending on the method of presentation of stimuli, and the freedom of the subject to control his feedback. Those two types of experiment may be termed (a) array sorting, and (b) serial sorting experiments.

In array sorting, subjects are presented with any array of instances and are required to sort them into groups.

In serial sorting, instances are presented in sequence, either pre-determined or random, and subjects are asked to make a placement of them in groups according to desired stimulus attributes.

In array sorting, the subject receives feedback about choices he makes as to whether he is right or wrong, but he is also free to select the next instances because the array is displayed before him. In principle this allows him to choose instances so that he can maximize the information in the KR.

In serial sorting, the subject is shown one instance of the concept and must choose whether or not it is part of the concept; then he is told whether he is right or wrong. Here, the experimenter can control the next instance in the sequence and therefore the subject cannot maximize information received from knowledge of results.

The importance of a "program" model of information processing is more immediately evident when we turn to look at concept formation experiments than for skilled performance experiments, in part because the individual is required by the design of the experiment to adopt a more active exploratory role. The description of the "strategies" employed by subjects given by Bruner and his associates conforms very well to the model of subroutines: subjects tend to follow well-defined strategies, "conservative focusing", "focus gambling", etc. The amount of information to be gained from a stimulus depends, in part, on the subjects previous choice. This considerably extends the concept of the choice reaction experiment, and allows us to place it in a different perspective: as a subclass of sequentual choice experiments which do not encourage hypothesis-formation.

Bruner and his associates found, among other things, that the choice of strategies varied systematically as a function of the informational, strain, and risk characteristics of the problems. Information was varied by both amount provided and by the form (positive versus negative instances). Cognitive strain was varied in several ways, of which the one most salient to our earlier discussion was a stepping up of the pace of presentation. Under conditions of moderate information and low cognitive stress, subjects followed a program certain to provide a certain amount of information per choice. Under no time pressure, this "strategy" guarantees eventual success. When time and other limitations were imposed, it was found that subjects tended to shift to a "strategy" in which, if they were lucky, they could obtain much information quickly, but which involved considerable risk. It was also found that under pressure of time subjects tended to fall back on cues that seemed in the past to have been useful, cues that were most easily available or most easily discriminable. Finally, they noted that under accelerated time pressure, subjects began to cast about in search of almost any available piece of information, even though the result was to overwhelm their limited information-carrying capacity. It appears that with increasing stress, ~~the~~ strategies show a tendency to degenerate from orderly systematic search towards random search. (Perhaps the latter is an example of what Miller terms the "confusional state").

A further limitation discovered by Bruner, Goodnow and Austin can be traced to limitations of memory. The subject is required to store the results of previous positive and negative choices. It is for this reason that Bruner et al. hypothesize that "negative" instances tend to be underutilized by subjects: a greater memory strain is involved.

In other research, Schroder, Driver and Streufert (1967) used a war game simulation which required subjects to integrate available information in order to issue a series of commands resulting in the deployment of their forces on an imaginary island against a similar enemy force. The experimenters varied the amount of information presented, input rate, and the proportion of results called positive and negative. They found that increases in the rate of presentation of information at first improved the information processing performance of subjects, but that beyond a certain point severe decrements occurred. They also found, like Bruner et al, that negative instances depress performance. Under conditions of low stress, subjects used more dimensions of information than under high stress, when judgments tended to take on a black and white cast, stereotyped thinking become evident, and complexity of integrations declined.

The results reported by Schroder et al. support the view that under conditions of stress, it is the nature of the program followed by the information processor which is affected.

The internal environment

In the previous discussion it was shown that KR, knowledge of the results of one's choices, may be a source of information which is as important as stimulus information. In this section, we look at a further neglected domain, that of interoceptive stimulation.

The role of the reticular formation, and in particular of the thalamus, in the control of behavior in general, and the execution of many simple program of behavior, has already been noted. Adjacent to the thalamus in the brain stem is the hypothalamus, which is an important center for the control and regulation of visceral processes of the body, body temperature, and the glandular system. Hess (1957) found that stimulation of cells in the hypothalamus affected rate and depth of breathing, blood pressure, heart rate, and caused vomiting and body elimination. Appetite is apparently controlled by the hypothalamus: destruction of a part of this region will prevent an animal from eating no matter how hungry, or will cause it to keep on eating, no matter how satiated. In addition, emotion can be aroused in an animal by stimulation of hypothalamus sites, fear, hostility, rage. Additional work by Olds (1956), Brody, (1958) and others demonstrated the existence of pleasure and punishment centers in the brain, stimulation of which produced evidence of hunger reward, sexual reward, intense pain - in the absence of other external stimulation.

Since the body for its continued functioning, requires the maintenance of homeostasis within a great variety of subsystems (Cannon, 1932), it is not surprising that the system responsible for monitoring and controlling activities of the body should be closely associated with the program - directing mechanism of the body responsible for activity upon the external environment. The organism remains informed about states of the environment in two ways: (1) directly from the exteroceptive system, and (2) indirectly, as a result of changes occurring within the internal environment, which can be traced to changes in the external environment. We are becoming accustomed, for example, to measuring pollution as much by its effects on our internal good health, as by smell and tastes which often does not provide good information.[20] The state of the internal environment is of primary importance, since if its continued efficient functioning cannot be assured, the existence of the orga-

20) An ingenious use of this fact is illustrated in the experiments of Schacter (1964). Schacter induced subjects under another pretext to take epinephrine, which produces symptoms of palpitation, tremors, accelerated breathing. Schacter found that subjects labeled their emotion by reference to conditions in their external environment.

nism is threatened. The state of the internal environment is a criterion by which we sometimes evaluate states of the external environment. Beside beliefs stand feelings, beside intentions, wants.

Most choice reaction experiments have assumed the states of the internal environment to be constant; however, there is at least some evidence in the Schroder et al. experiments to indicate that effects of emotion cannot properly be disregarded. These experimenters found effects due to what they termed "noxity" and "eucity", roughly unpleasant and pleasant environmental reward. This suggests that the monitoring of changes of state, resulting in adoption of program change, and the evaluation of possible effects, in not restricted to those occurring in the external environment; the internal environment is also implicated.

The relation of communication to the information processing system.

The distinction between external and internal environments (and hence sources of information), while somewhat important in its own right has a more important indirect consequence.

The effect of communication, the consequence of symbolic interchange, is to link information processing systems. We ask people to tell us what they see, and act on what they tell us. We request opinions and advice. We issue instructions and others carry them out; we commit ourselves to certain types of program because of our relationships with others. Using Figure 3 as a point of reference, we may say that someone has access to direct experience of the external environment, but it may not be us.[21]

It has been too seldom noted that every linguistically-encoded message contains information on two essentially different levels: (a) referential information, and (b) relational information[22]. A sentence has some propositional content which refers to an external world. Such objectively informative statements are of two kinds: (a) reports, and (b) commands. Reports are due to the operation of processes of perception; commands are intended to result in the effecting of a plan.

The external environment we assume to be directly given to all of us through our respective sensory systems: we therefore need only refer, or point to, things in the common environment in order to communicate. By contrast, our internal environments are our own, and only we have immediate access to them. For each of us our basic knowledge consists not only of beliefs about the state of the external environment, including our explanations of its dynamics, but also of our feelings which represent the states of our internal environment. Not only "There are roses in my garden" but also

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21) The importance of communication has been seriously neglected in the literature on information overload with unfortunate results in limiting the generalization of the laboratory results to conditions within technologically advanced societies. Within the "wired nation" the increasing importance of symbol exchange may be confidently predicted. The individuals who will be subject to information overload in that society more likely than not will have had their information passed to them by someone else. The effects of this interdependence do not appear to have been examined experimentally. We may perhaps guess at one consequence by noting the widespread and apparently increasing phenomenon of viewer suspicion of the news services.

22) The following discussion reports in summary form work in progress by the author.

"I love the smell of roses".

The common information system which results from communication in a dyad has one external environment, but two internal environments. It seems logical to represent the latter as a set of ordered couples (Newcomb, 1953). This set defines a relationship. Every communication potentially carries relational information: it may specify whether the two believe the same things, have the same objectives, want, intend, feel the same things. Such information is never fully attainable by direct sensory experience: it can be arrived at only by inference.

Every human <u>needs</u> information and advice on what program to carry out. Every individual is <u>susceptible</u> to control, and hence to the omination of others, and ultimately to the accomplishing of the objectives of others, and the neglect of those of self. Each individual has to measure the implications of others' messages in terms of his own self-interests. Social roles can be defined by the messages appropriate to them: it follows that every message either reinforces or changes a role relationship. There is in all communication relations this built-in tension.

The experimental literature on information overload does not inform us what happens to communication, and to social organization, under conditions of information overload. A number of experiments (e.g., Hovland and Weiss, 1952; Kelman, 1958), show that information transmission is affected by the perception of relation; it has not been possible to discover any experimental evidence concerning the reverse situation, and particularly concerning the effects of information overload on the perception of relationship.

Summary and Perspective

The results of our survey may be summarized as follows:

In those situations which require the subject to make a pre-determined behavioral correlation between a stimulus ensemble and a response ensemble, and where information transmitted is indexed by the actual (when compared with the expected) correlation, then it can be shown that response rate and accuracy are a function of stimulus information. The function is U-shaped: information transmitted is a direct function of stimulus information up to, but not beyond a certain limiting value for stimulus information, beyond which, as stimulus information further increases, information transmitted at first levels off and then declines. This result, which is predicted by the information overload hypothesis, is not limited to laboratory conditions, but can be shown to have wider application in ordinary life conditions (Meier, 1962).

Against this primary conclusion we have to weigh the following:

The constraint is an output rather than an input constraint. This is explained in part by the finding that perception itself depends on output or output-controlled processes. The empirically determined limit thus appears to be not so much a function of information as such, as of inherent organismic limitations in organising and carrying out its own activities. The point is stated by Garner (1962): "It appears, then, that there are psychological factors involved in carrying out any timed task which are quite independent of information variables. Even though reaction time is a function of stimulus uncertainty, there are limiting factors involved in the carrying out of successive motor responses which are quite unrelated to information as such. There is, in other words, a limit on how fast any sequence of acts can be carried out, and this limit is almost entirely independent on how many motor acts per second are required".

Secondly the model of organismic functioning implied by the concept of channel capacity has been found to be at best a rough analogy (23). The thesis of information overload is based on assumptions concerning channel capacity, but experiments have not shown that channel capacity as such was exceeded, or indeed given any clear indication as to what channel capacity might be for humans. Of more significance is that in types of skilled performance experiment other than these requiring simple choice reaction, and for concept formation tasks, the model is found to be inapplicable. Yet in both learning and concept formation tasks, the capacity to handle varying amounts of information is vital to the continued successful functioning of the organism.

For these reasons, the "transfer function" model was abandoned in favor of a "program execution" theory of information processing behavior. Some of the evidence supporting a theory of efferent control of behavior was briefly summarized, and it was shown that this approach can be adapted to concept formation, as well as to skilled performance tasks (with or without learning) quite adequately. Finally it was noted that experimental attention had been until now concentrated on uncertainty in the external environment, to the neglect of states of the internal environment of information processors. Out of this discussion, it was observed that the relationship between information integration and transmission variables

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(23) cf. Garner (1962): "It is impossible to conclude....that humans are ideal information-processors - ideal in the sense of following exactly the requirements of a mathematical model."

and other communication variables, such as role, leadership, etc.. has been almost totally neglected.

What remains to be done? In our view, there are two main classes of question which remain to be considered in depth: (a) those associated with program overload, and (b) those which relate to the function of information transmission in communication.

One important conclusion which can be reasonably drawn from the previous discussion is that the real problem of the wired nation is not that of information overabundance as such but of the undertaking of two many separately interesting tasks which together result in the condition we term "program overload". On page 4 of this report it was noted that the introduction of new technologies has two consequences: while it augments available information, it also leads individuals to interact within wider networks. The latter fact seems to us to be the more important, - and the more neglected. It implies that individuals tend to get involved, simultaneously, in a number of transactions.

The danger of overabundance of available information can be easily exagerated. Several of the researches quoted would tend to lead us to believe that the underlying principle of human information processing assumes at all times information superabundance. The mechanisms of perception are adapted to inhibit, or suppress, unneeded and unwanted information. Milgram (1970) has demonstrated that individuals living in information-rich New York City exhibit equal ability to select needed and screen out unwanted information in this environment (which they chose indeed because of its information characteristics, as Mumford and other urbanologists have long been at pains to point out).

By comparison, the individual seems disastrously non-adapted to deal with program overload. This we take to be the significance of a recent article by Lipowski (1971), who argues: "a major feature of the affluent, technological and open society is that it exposes its members to an overload of attractive stimuli". Lipowski defines "attractive stimuli" as those which "arouse appetitive and approach tendencies". They involve his capacity to "process, choose, approach and consummate". In our terms, this would be re-interpreted as the tendency to become involved in more activities than can be adequately handled by the individual. The process is insidious: each new activity is initially attractive, and the individual may tend to underestimate its time requirements over a longer period. Eventually, he is committed to more activities than can be managed at once, each with accelerating information processing requirements. The final product may well be confusion and breakdown.

The evidence we do have indicates that program overload can prevent successful concept formation, and hence reduce the individual to stereotyped responses: As Meier (1962) writes: "The culture of cities cannot grow and develop unless man's interpretation of the universe and man's study of man supplies new concepts and images more rapidly than they are lost".

Communication and Information

The second question which has received little attention in the available literature is the role of information transmission in communication. To a surprising extent, we have been led by the influence of a communication model based in engineering research to suppose that the analysis of information systems could be conducted without regard to other communication variables. This situation needs to be rectified, particularly since it is at this level, above all others, that the social (as opposed to the psychological, discussed in the previous paragraph) effects of technological innovation will be most evident.

We reason as follows: man <u>requires</u> information (verification and comparison of his hypotheses and perceptions), but he is <u>vulnerable</u> to control. Communication has as one effect the linking of information transmission systems into chains, in which (because of the symbolic capability of man) one can serve another as his eyes and his hands (Figure 3). It is because of the "control" dimension of communication, even more than because of the informational, that individuals establish systems made up of statuses and roles, which (a) assure to individuals a certain stability in their communication relationships, and (b) create the basis of an organized society. What has not been asked in the literature on information overload is the effect that intensified information processing may be expected to have on the social structure which the information-control system supports. As the individual becomes overloaded, does the resulting stress make for increasing dependence on others? Or decline in trust? Under conditions of overload, does it become increasingly difficult to organize the necessary social arrangements? Does comprehension decline? Are there effects on how much information is accepted from others?

The answers to these and similar questions cannot be found in the existing literature, yet this information is of increased urgency: it will have gained us little if in extending our means to communicate with each others, we succeeded, in the process, in destroying the very basis on which our society can be organized. We need to learn not only how to handle more information, but at the same time how to re-organize the accompanying social arrangements: "The breaking up of....organization, or its reduction to impotency due to communications overload, is....frequently due to inadequacies in the basic formula for doing business or in the informal 'rules of the game' set by occupations and professions" (Meier, 1962).

The study of overload must be made to lead, ultimately, to the discovery of adaptation.

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