COMMITTEE I
Unity of Science: Organization and Change in Complex Systems

DRAFT - 8/15/85
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MIND : MAPPING AND RECONSTRUCTION OF REALITY

by

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The Fourteenth International Conference on the Unity of the Sciences
Houston, Texas November 28-December 1, 1985

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Percy Löwenhard

1. Some ontological remarks on reality and order.

> Here and elsewhere we shall not obtain the best insight into things until we actually see them growing from the beginning ....
>
> ARISTOTLE

The main title of this paper implies two ontological statements: the existence of an external reality, independent of an observer, and the existence of that function of our brain which constitutes the universe of subjective experience: the mind.

The world as we see it is a world of perpetual change and evolution. At least it appears to us that parts of it show time sequences which alternate between states of chaos and perfect order. Within the realm of changing complex systems, living organisms are the most salient proponents. They are not only the result of a very complex evolutionary process, which has taken place during billions of years, but one of the results of this process, the human brain, is able to transfer the application of organizatory principles outside the boundaries of the organism itself.

The human brain is one of the most marvellous achievements of nature. It is not only the most complex single structure in that part of nature which is known to us, but its complexity includes the existence of functional principles whose details to a large extent are still more or less enigmatic. One may illustrate the meaning of this complexity if one considers the performance of the mammalian eye. The retina of the eye is functionally a part of the brain. If one wants to simulate the real-time information processing of a single retinal nerve cell, this would be equivalent to the simultaneous solution of about 500 non-lienar differential equations within a time-span of 10 milliseconds. The very fast Cray XMP supercomputer would demand a computing time of several minutes to perform this task (Stevens, 1985). Now, one has to consider that the information processing of the retina involves the simultaneous interaction of several millions of nerve cells. Finally, the cerebral cortex contains in the order of 10^{10} to 10^{11} neurons and 10^{13} to 10^{15} synaptic junctions. Hence, with respect to its integrative potential, the information processing capacity of the brain is truly stupendous. Some further details will be given later on.

Any description of such a system has to take several central concepts into consideration:

* The notion of hierarchically organized systems with dynamic interaction between all levels of their hierarchy.
* The notion of self-organizing systems, which has two aspects:
  a) A phylogenetic aspect, related to the concept of evolution in a Darwinian sense.
  b) An ontogenetic aspect, related to genetically controlled growth and development of an individual organism.
* The view that phylogenetic adaptation represents an information process. This means an interaction between organisms and their biosphere as well as between living systems and non-living matter or radiation.

Some of the basic principles which are related to the self-organization of lower-level systems are dealt with in previous chapters of this volume.

With respect to living systems, the above mentioned aspects are integrated within the relatively new thought model of evolutionary epistemology (see e.g. Campbell, 1974; Riedl, 1979; Vollmer, 1981; Lorenz & Wuketits, 1983). While this model is based upon the Darwinian concepts of evolution, selection and individual adaptation (including findings from embryology), it is not identical with the classical theory. Some intermediary steps are Neodarwinian Theory, which also includes genetics and chance mutations as a source of variability and finally "Synthetic Theory", which enhances its sphere to include population genetics and molocular genetics as well. To be precise, one must add that evolutionary theory is not a theory in a strict sense, but rather a bundle of theories from different disciplines within a common frame of reference.

Contemporary theory includes cybernetics and system theory. Essentially its models are much more complex. While mutations mainly are "blind" processes, survival of the fittest (selection with respect to a given environment) does not seem to follow a long term "teleological master plan" either. It may be added that "fitness" can be defined without reference to survival, which nullifies the allegation of a circularity (cp. Vollmer, 1982). Evolution then must not be viewed as the result of a chain of single, directed factors which influence a given system, but as a multicausal feedback process between interacting systems. The central postulate of molecular biology, the functional order

$$\text{D N A} \longrightarrow \text{R N A} \longrightarrow \text{protein}$$

must in some cases be modified because there are interactions between the different elements of the epigenetic system , which gives a more complex picture. The origin and evolution of living systems seems to be the result of an inherent dynamics of material systems, leading to an optimal adaptation. An excellent survey of these questions has recently been given by Wuketits (1985).

Phenomena such as "life", "consciousness", "matter", "space", "energy" and "time" seem to be basic attributes of our universe. They are, however, rent quality. Within physical theory, the nature of our world is ultimately described in terms of particles and interactions between them. The term "particle" here must not be interpreted as something akin to our everyday experience but as a quantum mechanical phenomenon with both "particle like" and "wave like" features.

As far as we know today, there are four different types of interaction (or forces) which in a near future perhaps may be united within a common theory. An up to date survey on this topic is given by Quigg (1985). Within the framework of our mesocosmic world, however, the electromagnetic interaction is quite dominant with gravitation at the second place. Electromagnetic interaction is responsible for a vast majority of everyday phenomena such as the coherence of matter, the molecular bond, chemical reactions, electric and magnetic phenomena and their different applications such as the generation and transmission of electric energy, the processing and transmission of information and so forth.

The phenomena of "life" and "consciousness",however, must be said to represent a higher ontic level (within the same basic ontology), where "consciousness"demands the previous existence of "life". Matter reveals a tremendous variety of properties and potentialities. One may mention its ability to organize itself into complex structures under suitable conditions, which is a precondition for the emergence of living systems. A critical factor is the existence of a universe which has a sufficiently low level of entropy and which allows for local variations of it. Furthermore, the emergence of life, as we know it, seems to demand the existence of a large set of favourable conditions: a planet of suitable mass, a critical distance from a sun of suitable spectral class, planetary rotation, a suitable composition of the geosphere etc. It is probable that the creation of order and life on earth has been made possible by the emission of low entropy (highly ordered) energy from the surface of the sun at 6000 K and a re-radiation of high entropy energy (infrared radiation) at 300 K (Sexl, 1984). Among other critical factors one may mention the homeopolar bond of carbon atoms (ensuring the formation of large carbon chains) or the large number of "abnormal" properties of common water: its ability to work as a nearly universal solvent, its density maximum at 3.9 degrees above the freezing point, its very high dielectric coefficient, its high boiling point and heat capacity etc. These properties which are due to the marked dipole moment of the water molecule, influence geology, the biosphere and molecular biology in a remarkable way. They also nicely illustrate the variety of effects which relate to a single factor: the molecular distribution of electric charges or in other words, the geometry of electromagnetic interactions.

2. Living organisms : Self-organization and complexity.

This paragraph will discuss some general features of living organisms amd the notion of life. Since the contributions of Dr. Pincheira and Dr. Villee deal in more detail with genetic and cellular functions, these are only mentioned cursorily here within contexts to which they relate.

The concept "life" is intutively well-known but shows a treacherous elusiveness if one tries to define it strictly. This is due to the intrinsic complexity of the phenomenon, but also to its wide range of connotations. Generally, the term "life" is a common label which we apply to the totality of organisms or living systems which constitute the biosphere of earth. The functional properties, which are necessary to sustain the continuous existence of living systems may be called their life functions. Organisms are a subset of living systems and are characterized by a particularly high degree of autonomy. Thus the term "life" may be used to denote the totality of life functions which characterize a given organism. Meanwhile, one must also consider the characteristics of life as a holistic phenomenon:

* The existence of life is dependent on the state of the system (living or dead). This means that life functions are strongly integrated and interdependent.
* The existence of a living organism is limited to a time-span between "birth and death".
* The system properties of an organism change during ontogenesis (evolutionary

aspect).

* The changes which the organism undergoes during its existence reflect the aspects of life as a process.

With respect to more specific features, the following characteristics are now viewed as sufficient conditions for life:

1. Metabolism 2. Reproduction 3. Mutability 4. Interaction between functional elements (e.g. proteins) and carriers of information (DNA, RNA).

Living organisms show furthermore a variety of additional properties, some of them specific, others common to many organisms:

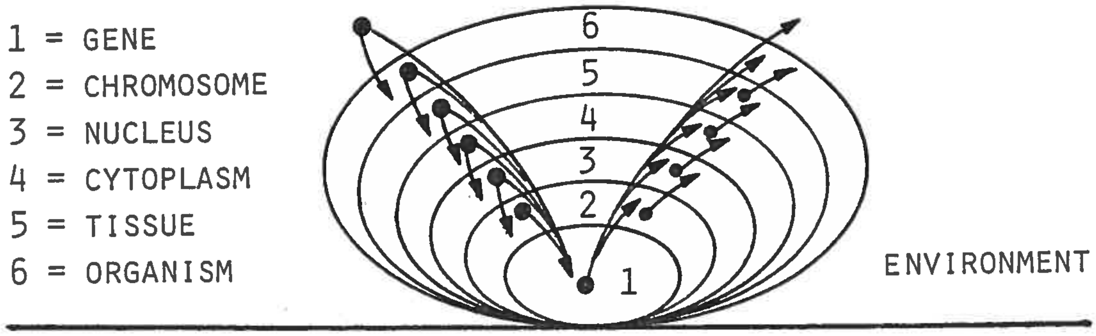
Activity - reactivity - homeostasis and self-regulation - self-mend and maintenance of structure - program-controlled growth - behaviour modification by learning - maintenance of negentropy - consciousness etc.

The complexity and multidimensionality of living systems could not be understood in terms of the mainly deterministic models of classical science. Later on the inadequate application of The Second Law of Thermodynamics to living systems seemed to be a further obstacle. It is important to remind oneself of the influence which the "Zeirgeist" or certain ideas may have on the promotion or impediment of scientific progress. An example of the latter are vitalistic theories which try to relate the existence of life to the effects of a non-physical "life-force". Other difficulties arise if one tries to introduce teleological principles, related to the "purpose" or "meaning" of life. A comprehensive survey of these problems has been given by Wuketits (1982). During the 18^{th} and early 19^{th} centuries, "organic" compounds were thought to depend on living organisms for their existence (the notion "organic" for carbon compounds still reminds us of this fact). The synthesis of urea (an animal metabolite) from "inorganic" ammoniumcyanate

$$NH_4CNO \longrightarrow (NH_2)_2CO \quad \text{(urea, carbamide)}$$

was performed by Friedrich Wöhler in 1828. This was not only a contribution to the chemistry of carbon compounds, but it questioned the validity of vitalistic theory with respect to organic compounds. The example illustrates nicely how our opinions about which questions principally can be answered (in this case the relationship between organic and inorganic matter) is dependent on the actual level of empirical knowledge. Nevertheless, varieties of vitalistic theories prevail up until today. An example is Rupert Sheldrake's hypothesis about "invisible morphogenetic fields". These are essentially corresponding to ideas which have been expressed earlier by the German biologist and philosopher Hans Driesch.

Basically, living organism are very complexly structured chemical systems. With respect to this fact, biology favours a reductionistic view. Nevertheless, reduction then leads to the problem of handling complexities. Also, one has to consider the problem of emerging properties . In the sense of General System Theory (Bertalanffy, 1952, 1973; Laszlo, 1973; Weiss, 1969, 1971) living organisms are hierarchically organized, stratified, multi-levelled systems with dynamic interaction between all levels. According to Weiss (1971) this may be illustrated by the following figure:



The model does not only imply an interaction between all levels of the hierarchy, but a simultaneous superposition of their working principles. This means that living systems form integrated wholes. The intricate multidimensionality of such systems is clearly shown in the excellent work of James Greer Miller (1978), which gives both an extensive and comprehensive treatment of the topic.

Due to the complexity of living systems, the probability of their occurrence by chance is infinitesimally small. While chance events undoubtedly play an essential role in evolution, any unqualified random shuffle theory falls short in accounting for the large variety of organic systems which constitute the biological sphere of earth. One has to introduce additional assumptions:

1. Besides the tendency of matter to organize itself, there exist restrictions which drastically cut down the number of functionally stable combinations of elements. At the atomic level one may think of quantum numbers and the exclusion principle of Pauli (see e.g. Alonson & Valk, 1973), at the biochemical level one may mention the specificity of protein reactions.
2. The development of the life-forms of today must have been critically dependent on the number and distribution of potential intermediate stable forms. Nature seems to conserve successful stages of evolution. These systems then may either be used as building blocks for higher order systems or be subjected to further adaptive medifications (cp. Laszlo, 1973).

During growth and development the complexity of the organism increases steadily. This means that growth implies the occurrence of consecutive states with steadily decreasing probability. In order to maintain structure and life functions intact, the organism has to rely on well established and stable principles of self-organization, homeostasis and self-mend. In a certein sense mechanisms of defence and the ability to modify the environment as to fit the needs of the organism may be looked upon as an extension of homeostatic functions outside the physical boundary of the organism. Their task is to prevent any disruption of the organism's life functions and integrity.

Any description of such a system must take all the above mentioned features into consideration. A supersystem may show emerging properties which cannot be predicted solely from the knowledge of it's subsystems, since some holistic features of the supersystem may not be reducible. The principle of superadditivity (Leinfellner, 1984) represents a sophisticated way to describe this fact.

This also holds for the relationship between living systems and the implicit information of their genetic determinants. A sequence of codons (triplets of nucleotides) determines the order of aminoacids within a protein. However, in order to know the function(s) of this protein in a given biochemical environment, one has also to know the chemical properties of this specific array of aminoacids as well as the distribution of hydrogen bonds, which ultimately determine the secondary or tertiary structure of the protein and thus, for example, its enzyme functions.

Generally speaking, any detailed description of living systems makes at least a partial reduction necessary. Essentially this means that such systems cannot be described in terms of concepts from a single science, but elements form "higher order" sciences as well as from more "basic" sciences have to be included. While there is a strong interdependence of sciences with respect to concepts and methodology, each scientific discipline also develops methods, concepts, rules of the thumb and theories of its own (some more details are given by Löwenhard, 1984). Suppose that one wants to describe the chain of events which ultimately results in a conscious perception; then one has to start with the specific interaction between a receptor and the stimuli which convey physical energy. With respect to vision this means a photochemical excitation of photopigment molecules (rhodopsin or iodopsin) within the retinal receptor elements (rods or cones). The first event is, hence, a quantumchemical event, the absorption of photons (light energy), followed by a dissociation of the photopigment molecule. In the case of rhodopsin this is accompanied by a cis-trans conversion of retinene (aldehyde of vitamin A) which is the chromophoric (specifically light absorbing) component of the photopigment molecule. The chain of further events finally results in a generator potential by interruption of an ion current which normally passes through the plasma membranes of rods or cones; (details are given by Gemme & Bernhard, 1975 or Zurer, 1983).

Concerning hearing one has to start with the transfer of the complex amplitude-time function of a sound wave to the phonosensitive mechanism of the inner ear. This mechanism works in an aqueous environment. Since the transfer of sound energy between media of different acoustic density is usually very inefficient, the lever system of the middle ear performs the task of conveying the oscillatory movement to the inner ear, faithfully conserving the amplitude and phase relationships. In the next step then the hair cells of the inner ear transform the mechanical oscillations into corresponding electrical ones. These microphonic potentials (choclear microphonic, Wever-Bray effect) are essentially equivalents of piezoelectric potentials which result from a periodoc elastic deformation of certain crystals such as quartz or the organic Seignette salt (potassium-sodium tartrate).

Further details will be omitted here, since they demand a space-consuming treatment of more intricate functional anatomy. For details see e.g. Lindsay & Norman (1973).

A common task for all sense mechanisms then is to convey both general and specific information from the stimulus to the higher levels of the brain. Primarily the information has to be encoded into a common language of nerve signals which allows for a comparison of messages from different receptors. Essentially there are two known principles of encoding:

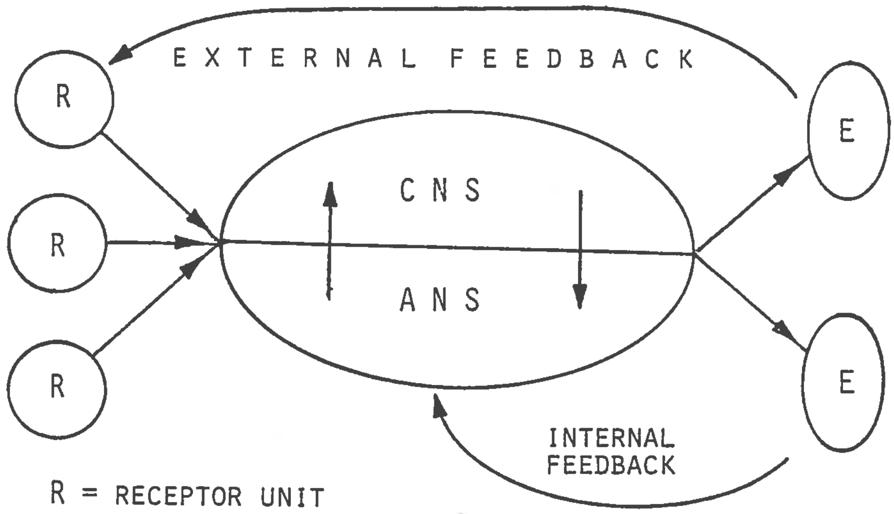
1. The information content of nerve signals is related to their spatio-temporal pattern (comprising the cooperation of several nerve fibers).
2. The information is identified by the channel through which it arrives. This principle of "specific termination" may be regarded as a modern reformulation

of Johannes Müller's famous doctrine of "specific sense energies" from 1826. Some more details will be given in the next paragraphs. These short examples illustrate the above mentioned thesis of scientific interdependence in the description of living systems.

A final example will conclude this paragraph. With respect to the concept of life, the hierarchical structure of all organisms implies that "life" means partly the same, partly different things at different levels of the same organism. If an animal is killed the organism as a whole dies. Nevertheless, an organ, for example the heart, may be surgically disconnected and placed into a suitably oxygenated solution of nutrients. Electrical stimulation may induce a continuation of its life functions. The organ as a living subsystem may thus be preserved a long time after the death of the organism to which it once belonged. Carrel and Lindbergh (1938) have demonstrated this nearly 50 years ago.Now, the life functions which are pertinent to the performance of the heart within the organism may be disrupted, but some of its cells may be kept functionally intact and may be stimulated to grow and to multiply. But even if the cell dies as a basic living subunit, some of its fundamental functions persist outside the cell body: the contractile properties of the actino-myosine molecules (two types of specifically interacting proteins) which are responsible for the muscle's ability to contract and to perform mechanical work. The contraction of muscle cells in vivo is controlled by higher order mechanisms, related to the organ. If actino-myosine now is dispersed into a suitable solution of nutrients, contraction of the protein-aggregate may be triggered in vitro by ATP (adenosine triphosphoric acid, a molecule, able to deliver energy) (Fulton, 1956). This example shows that there is a distinct holistic difference between <u>any</u> system in a "living" and a "dead" state.

3. Brain and CNS : the physiological basis of information transfer.

The earlier paragraphs have dealt with some main features of living organisms and also touched upn the question how an organism retrieves information from its environment. Within the animal domain the brain and CNS form together with receptors the information system of the organism.



R = RECEPTOR UNIT
E = EFFECTOR UNIT (MUSCLE OR GLAND)
CNS = CENTRAL NERVOUS SYSTEM;
ANS = AUTONOMIC NERVOUS SYSTEM

It is evident that no detailed description of the brain's functional anatomy could be given here, but the topic has to be limited to general principles. Normally one has to make a distinction between anatomical structures and functional systems. The eye, for example, may be viewed as a single anatomical unit,but contains two functionally different subsystems: an optical system which projects an image of the external world onto the retina and an information processing system which performs an analysis of the retinal light pattern. Essentially, there is no one-to-one relationship between anatomical structures and functional systems. Otherwise one would easily end up in phrenology. The structural unit of the CNS is the nerve cell or neuron, while nerve nets constitute the functional units. The existence of a certain nerve net may be restricted in time or not, while the structural components are more stable. An analogy may illustrate this. Telephone communication is based on the creation of a temporary communication line by connecting a subset of existing wires into a functional unit. This is done with the aid of relays which are controlled by a coded time sequence of electrical impulses. In a similar way the brain utilizes associative networks which may be said to connect a set of input channels with corresponding output channels in a manner which optimizes information processing with respect to a given problem (cp. Crick, 1979). The brain is both an open system and in a sense a cooperative system.

An understanding of the working principles of our brain has been facilitated by computer technology, which in turn has profited from brain research. Thera are similarities between brains and computers, but also essential differences. Basically both are information processing systems, but one may argue that the brain primarily is an instrument for survival, since sufficiently detailed knowledge about our world makes it somewhat more safe. The brain is the result of an essentially "self-sustained" evolutionary process, while the computer is designed and presupposes the existence of brains. The computer depends on deterministic principles, components of high reliability and the use of rapid sequences of electromagnetic pulses. The brain uses partly stochastic principles, its design is only roughly deterministic and it is rather insensitive to the failure of single neurons. As a chemical system it depends on rather slow processes of ion transport through membranes, but uses many lines in parallell. It has a high degree of economic flexibility and performs a sophisticated processing of information at the synapses. Its partly digital, partly analog mechanisms have lately revealed a capacity which still today surpasses that of computers by many magnitudes. An illustr tive example has been given in the first section of this paper.

Animal organisms use two types of information systems in parallell:

1. The nervous system, which starts rapidly, but mainly has effects of short du-

ration. There are but mechanisms (neural loops or repeated activation), which may ensure more enduring actions. There are two types of information processing:

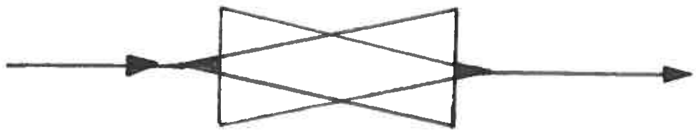
a) Long range transfer of information is based on the mediation of action potentials (nerve impulses) in conducting fibers (neural axons) and may essentially be compared to telegraph lines, utilizing a digital (all or none) code.

b) Local information processing is based on the intricate interplay of graded slow potentials and chemical processes. The local synaptic junctions may use chemical transmitter molecules (neurotransmitters) or the effects of local electric fields (electrotonic synapses). There also seem to exist mechanisms which perform analog-digital-analog concersions (John, 1968).

2. The endocrine system starts slowly, but has an enduring action. It utilizes signal molecules (hormones) which are injected into the blood stream and in this way are distributed all over the organism. They affect, however, only specific receptors, which chemically respond to a certain hormone. Receptor sites may be located at glands (which allows for hormonal feedback mechanisms), at other organs such as the heart, or at the synaptic junctions betwwen neurons. The transfer of nerve signals from a presynaptic to a postsynaptic neuron is mediated by neurotransmitters, which in some cases are identical with hormones. In this way the nervous system and the endocrine system are able to interact at the synaptic junctions between neurons.

This interactive duplicity of information processing is the reason why a change of the biochemical environment of a synaptic system may change the information content of a message which passes the system. The action of psychotropic drugs may be viewed in this way. Their medical use is aiming at a re-normalization of a distorted message.The use of different neurotransmitters in different subsystems of the CNS makes it possible to have a local web of functionally different nervenets, which are functinally separated from each other and do not interfer. They may, however be engaged in an independent control of the same higher order function.

Long range information transmission is not solely strictly linear, but convergence and divergence of information seem to occur simultaneously.



Divergence may be illustrated by the mediation of pain signals:

1. A single train of nerve impulses may originate from a small group of "pain receptors" (possibly nerve endings).
2. After having passed several relay stations, the signals engage at the spinal level already five different pathways.
3. Several cortical and subcortical structures are activated and perform a partial analysis of the incoming message. They then contribute to the pattern of signals.
4. The final brain state, corresponding to the perception of pain, represents complex information about the site and type of injury, the intensity of pain, its emotional aspects in relation to knowledge about the danger of the injury, the attitude of the person towards pain within a social context etc. (Melzack, 1961).

The second example shall illustrate both the principle of convergence and some aspects of synaptic functions with respect to quantitative information processing. The eye receives in the order of 10^8 bits of information each second, while only about 50 bits/s are recorded at the highest levels. What happens to the rest? One may assume that each nerve impulse corresponds to one bit. In order to trigger a postsynaptic nerve impulse, a minimum number of input impulses have to summarize their effects at a given synapse. This includes a superposition of both excitatory and inhibitory effects within a limited period of time.

Suppose that an equivalent of N excitatory input impulses is needed in order to trigger a postsynaptic neuron within a critical time period Δt (the effects of input signals are of short duration). If N is a large number, the probability is very small that the postsynaptic neuron is triggered by spurious "dark noise" signals. Hormones may change the threshold value of the synapse, i.e. the number N (or alternatively the period Δt). This mechanism means that the synapse works as a coincidence detector with independently controlled time constant. The synapse however, reduces the number of bits which pass the synapse by a factor 1/N. This "degradation" of information in a quantitative sense means that the system pays with information in order to gain certainty whether something at the output really corresponds to something at the input (McCulloch, 1951). But this also reflects a change in "quality" : a large amount of "raw" information at the input emerges as a small amount of "refined" information at the highest levels of the CNS.

This may be the place to make some remarks on information, entropy and order. The aspect of entropy which is relevant here appeared first in statistical mechanics. Energy states of high entropy have high probability. So have sysstems with high degree of randomness (lack of order). The thermodynamical entropy (S) of a physical system (of molecules) is according to Boltzmann a logarithmic function of the thermodynamic probability (P) of its occurrence:

$$S = k \cdot \ln P$$

(k = Boltzmann's constant = $1.38 \cdot 10^{-23}$ J/K. Strictly speaking, P is not a probability in a statistical sense, but a large number denoting the amount of possible microstates that correspond to a given macrostate. However, the thermodynamical probability is proportional to the statistical; see e.g. Fermi, 1956).

In a similar way the concept entropy appears within The Methematical Theory of Communication (Shannon & Weaver, 1959). The information content (H) of a message (information theoretical entropy) is a negative logarithmic function of the probability P_a of its elements.

$$H(A) = - \sum P_a \log_2 P_a$$

(a are the elements of an ensemble A (a message); $\log_2 P_a$, 3, 14, 16, 23, 33 etc. if binary logarithms are used). H then denotes the <u>average</u> number of bits which are necessary to identify an element of the ensemble. It may be added, that the concept H is not lomited to discrete functions or stochastic processes, but may be related to any probability density function $\phi(x)$ of a stochastic variable x:

$$H = - \int_{-\infty}^{+\infty} \phi(x) \log \phi(x) \, dx$$

(the integral denotes essentially an infinite summation with respect to a continuous function). Thus both types of entropy and the concept of information are related to the probability of the state of a system. The main formal difference is the minus sign. The relationship between the concepts has been interpreted so that information theoretical entropy (information content) can be viewed as a negative function of thermodynamical entropy, which means that H increases as S decreases. This gave rise to Brillouin's and Wiener's characterization of information as negative entropy or negentropy (Wiener, 1961; Brillouin, 1962). The deeper implications of this relationship have, however, been the object of different interpretations. (A more detailed discussion of the entropy concept and its different aspects is given in the paper of Dr. Sexl).

The transfer of information to a living system means essentially the transfer of organizational or structuring principles which increase the order of the receiving system. Living organisms receive a vast store of basic information through genetic instructions, which are encoded in the DNA of genes (order through order).

Later on the organism receives information through sensory processes and stores it in different types of memory.

Meanwhile, one has to be careful with respect to some differences. Shannon's theory is formulated for closed systems, which presuppose the existence of established channels, transmitters and receivers; no net energy is transferred to the receiving system, only information. All living systems, however, are open systems, exchanging energy and information with their environment. Hence, one may assume that information is gained by different processes at different stages of ontogenetic development and by different processes at different levels of the hierarchy. Transfer of information in the sense of Shannon's theory starts in connection with learning and feedback processes, when the necessary mechanisms have been developed. The transfer of information is then restricted to certain structures, which at the given hierarchical level[1] of the organism behave as closed subsystems. The transferred information then is encoded in a way which confines it to the boundaries of these subsystems. It must be assumed that the internally coded information is comparatively stable to the distorting influence of metabolic processes which always bring about a change of thermodynamic entropy.

4. Conscious information processing : control and creation of internal order.

An essential feature of the brain is its ability to detect and record its own states. The brain works as an autoanalytical instrument. Nevertheless, it is possible to accomplish certain autoanalytical functions with the aid of a computer, if a suitable hierarchy of analyzing programs is available, where higher level programs evaluate and change lower level programs with respect to external criteria of efficiency. But the brain has an advantage in that it is endowed with the superior principle of conscious information processing; it means that certain nerve nets seem to be able to sense their own states within the realm of their own functional level, but may simultaneously have access to other levels as well. This reflects both the peculiar self-referring or reflexive property of such systems and the holistic nature of the phenomenon of consciousness.

The brain is self-organizing with respect to its handling of information. The really marvellous accomplishment, however, is its ability to create by itself the programs which perform this task, even if one has to assume that the necessary prerequisites are genetically determined. The brain runs without anyone telling it how to run.

Since the term consciousness is used in a variety of ways, it is necessary to clarify the use of terminology within this paper. Due to the limitation of space, only some main features of the phenomenon can be treated here. For further details see Löwenhard (1981, 1984).

Consciousness is used as a technical term to denote what in a subjective language is called awareness or subjective experience.

Sensation is used as a general term to denote the effects in terms of subjective experience of the activation of receptors. A clear distinction is made between the phenomenon of consciousness as such and mental objects (symbols, images) which represent the information content of the conscious brain process.

Perception is defined as the conscious interpretation of sensory messages in terms of earlier experience.

Feelings is an ambiguous term which is used to denote unspecified qualities of awareness which are neither related to mental objects nor to specific emotions, acts of will or motivational states (hunger, thirst etc.). One should note, however, that "feelings" in everyday language include moods, emotional and motivational states as well as sensations such as pain (Jaspers, 1948; Zethraeus, 1962).

Mind is used as a label to denote the "non material universe of mental phenomena" , i.e. "World 2" in the terminology of Karl Popper (Popper & Eccles, 1977).

It is the conceptual framework to which all phenomena of conscious experience are related. One should note, however, that the term in this paper

1. does not imply any connotation of an internal homunculus (see Crick, 1979);
2. does not imply any dualistic ontology in the sense of Descartes (cp. Eccles 1970).

The following statements are either speculative hypotheses or descriptions of observable phenomena, related "consciousness". While some people want to restrict the use of the term to the human level, it is used here in a much wider sense. "Life" and "consciousness" are analogous phenomena, but there is an essential difference: "life" can at least principally, be explained in terms of earlier known principles, even if many details are still obscure. Contrary to this, "consciousness" holds features which presently are outside the realm of a strict scientific treatment. This does not mean that they will be so in the future.

1. Consciousness seems to be restricted to a certain class of living organisms which are equipped with nervous systems. It is a phenomenon which accompanies certain modes of information processing, characterized by the above mentioned ability of nerve nets to "sense" their own states. Subjectively we speak of a direction of attention onto the information content of the ongoing process. It is essential to make a distinction between

a) the participation in an immediate act of experience, i.e. "to be aware",
b) the actual information content of the ongoing process (object of awareness),
c) a knowledge about the principles which underly the emergence of consciousness as such, distinct from the coding principles of internal information. Both, however, may be the object of (b) and of conscious experience.

2. Consciousness seems to arise due to system properties which contemporary computers lack. Probably is it not solely a consequence of the systems complexity as such, but reflects inherent properties of neurons to which the phenomenon is

related. The critical system parameters are, as yet, not known. They may be related to the cellular level, to the subcellular level or to both, but consciousness seems to manifest itself only clearly in sufficiently complex systems. Nevertheless, the genetic instructions which govern the development of conscious nerve nets have to be encoded into the genome as part of the explicit and implicit genetic information.

While the brain is a physical object which has a spatial structure and a limited existence in time as a living system, mind seems to be a holistic phenomenon, which somehow reflects a non-locality, but has a definite extension in time. This indicates the intimate relationship of consciousness to brain-processes. The conscious brain state may be dependent on patterns of slow potentials and discrete pulses (bioelectric fields) which are related to aggregates of nerve cells and which fulfil certain (yet not known) conditions with respect to spatial and temporal continuity ("world lines"). A model of this kind has been proposed by Culbertson (1963,1982); it contains the above mentioned features under the heading of "historical causality".

3. Information processing proper and particularly conscious processes are related to activities of the cerebral cortex , which covers a total area of about 20 dm^2. The cortex is functionally divided into several millions of modules (or columns) , each containing many thousands of neurons, which are arranged in the well-known six layers of the cortex.

Each module may be compared to a "chip" (IC-circuit) of a computer and takes care of a certain type of local information processing. One should note, however, that all neurons are engaged simultaneously in the performance of different tasks. Memory functions, for example, may be common to all neurons. There exists an extensive web of interconnections, which virtually comprises all of the cortex and subcortical structures as well. In this way each part of the cortex is able to contribute in a specific way to the total conscious experience. The interconnected network renders it possible for the brain to perform the functions of a cooperative system, thus creating the impression of an integrated mind. Notwithstanding lateralization of some brain functions such as speech (hemispheric specialization), each hemisphere is a brain in itself, although they normally act together as a unit. There are two types of clinical observations, which show that each hemisphere is capable of producing its own conscious experience:

(1) Observations on split-brain patients, where the corpus callosum (=the great cerebral commissure) has been surgically dissected in connection with severe epilepsia.

(2) Total hemispheric anestesia, produced by unilateral injection of a hypnotic drug (e.g. amylobarbital) in connection with cerebral angiography (X-ray contrast mapping of cerebral blood vessels).

Further experimental evidence has been gained from the animal domain; (Sperry, 1964; Gazzaniga & LeDoux, 1978).

4. Consciousness seems to change with respect to both quantitative and qualitative features as a function of the complexity of the nerve net to which it is related. Thus, in analogy to life, consciousness means partly the same, partly different things in relation to different brains. One may assume that consciousness has developed alongside new system properties of living organisms; it means an increase of both quality and scope from primitive awareness at lower phylogenetic levels to abstract thinking and self-consciousness in man. Elementary mental functions have been shown to exist in very simple organisms and systems of neurons (Kandel, 1979; Sokolov, 1981).One should, however, be careful not to project human modes of experience into other animals. There is reason to believe, that the perception of the external world shows species-bound variations, which reflect the adaptation to a certain ecological niche. As early as 1928, von Uexküll

stated "that it would be a very naive sort of dogmatism to assume that there exists an absolute reality of things which are the same for all living beings. Reality is not a homogeneous thing, having as many different schemes and patterns as there are different organisms".

Conscious information processing seems to represent a principle which combines high efficiency regarding sensory discrimination with economy regarding the necessary number of neural elements (Culbertson, 1963). A principle which represents superior qualities is likely to be preserved in evolution and will probably be "adopted" by all organisms which can make use of it. "Human consciousness, like learning,is the product of evolutionary bias towards life forms with superior negentropic flexibility[2], for conscious life forms excel in their ability to receive information and to apply it under a wide variety of living conditions". (Sayre, 1976, p. 139).

Any organism which is confronted with the task of coping with its adaptation to a very complex environment not only has to integrate a large amount of different information, but this has to be done in a way which makes it possible to optimize a holistic response. Such a task includes, for example, the probability matching of different sensory messages in space and time in order to reveal their possible causal relationship. An appropriate behaviour within a given context has to be based on a processing of information which includes an internal representation of the organism itself together with elements of its environment. An animal which successfully wants to jump over a cliff has to judge its own trajectory in relation to distance and initial acceleration (a more detailed discussion is given by Jerison, 1978).

5. The barin uses both conscious and non-conscious modes of information processing. Strictly speaking, one has to make a distinction between unconscious processes (information not retrievable except by inference), subconscious pro-

cesses (information retrievable under appropriate circumstances) and non-conscious processes (information not stored in memory); (Hilgard, 1980). Normally different modes of information processing are used simultaneously.

Our conscious experience is characterized by content, modes of consciousness, states of consciousness and sense modalities. Different modes of consciousness seem to be related to different processes, e.g. different stages of information processing. A model of this import has been proposen by Aurell (1979, 1983). It is well-known that the vivid and clear experiences during sensory perception are different from the pale reproductions of past memories. Actual perception demands both cortical arousal (defined in terms of phasic physiological responses to sensory input) and activation through subcortical mechanisms (reticular activation system) , defined as a tonic physiological readiness to respond (Pribram & Mc Guinness, 1975). Nevertheless, there exist conditions during which images may gain the qualities of actual perceptions : hallucinatory states, hypnotic states or intoxications.

Different states of consciousness correspond to different neurophysiological brain states. One makes a difference between normal states (NSC) and altered states of consciousness (ASC). ASC occur naturally during sleep; there are also transitory states, such as the hypnagogic state, the transition from wakefulness to sleep.

Sense modalities are known from experience. It is a different sensation to see or to hear. A given modality cannot be transformed into another. It is normally not possible to image "what a sound looks like" or "how a colour smells". Sense modalities are distinct sensations which contribute to the stability of our perceptual world. Even if a person suffers from a grave intoxication, he is normally able to tell whether he hears or sees something, independent of the possible hallucinatory nature of the experience.

6. The content of conscious experience may broadly be divided into two classes: mental objects, which represent sensory information from the external world and feelings, emotions or motivational states, which represent changes in the physiological state of the organism. The latter have their importance as manifestation of mechanisms which control, organize and direct behaviour.One should note that any conscious experience always represents a mixture of cognitive, emotional and other elements. This is a subjective equivalent of the earlier stated principle of superposition of different systemic functions.

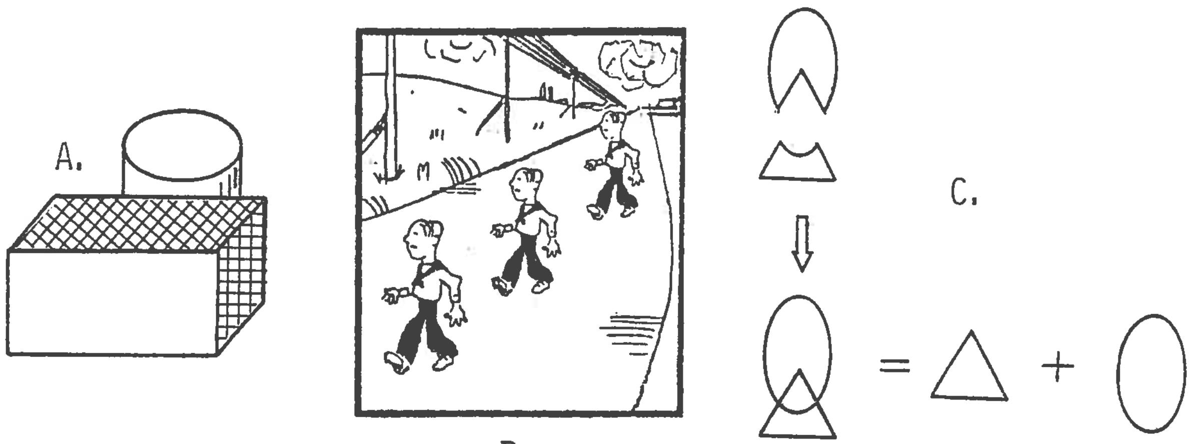
Mental objects correspond to an internal mapping of the external world. They are not simple projections of external objects,but sophisticated cognitive constructs, based on selective information from the environment. One has to remind onself that only a fraction of existing information is directly available to our senses. Our visual world consists of three-dimensional moving objects, which change their distance and position, but nevertheless are perceived as constant objects. Also there is an integration of temporal sequences of information into a single momentary sensation, which represents the elementary time span of conscious experience.

Innate brain mechanisms largely determine the way in which we perceive our world. They are part of the basic setup of automatically working mechanisms onto which the organism has to rely. Perceptually controlled behaviour depends on the action of triggers and filters, which activate innate programs under appropriate circumstances. Examples are:

* Instinctive behaviour which is elicited by a specific stimulus pattern and mainly consists of a predetermined, rather stereotype chain of actions.
* Imprinting, which means an act of learning during a critical period of an organism's life. Essentially, the process means that an innate program which governs a certain behaviour is coupled to an external stimulus object, which selectively

activates the associated trigger mechanism.

* Mechanisms of perception determine the way in which stimuli are analyzed and they contribute thus by means of given principles of analysis to the perceptual stability of our world. One may mentions depth perception and the tendency to perceive certain two-dimensional figures as three-dimensional objects (figure A). In spite of the continuous change of retinal images, we perceive corresponding objects as being constant (figure B illustrates size constancy). We normally analyze complex figures in terms of simple harmonic elements, so called "gestalts" (fig. C). This also applies auditory perception with respect to "temporal gestalts". Elements of human speech may be an example.



A. B. C.

The brain shows innate expectations to regard three-dimensional objects as solid. All the above mentioned features have been shown to exist at a very early age (Bower, 1966, 1971).

* If we look at a set of moving elements, e.g. dots, we perceive a spontaneous organization in that all elements which share a common motion form a group. This group may constitute a known figure or not. Subgroups are formed by elements which show a motion in relation to the common group,but simultaneously share the motion of the latter. The movement of arms and legs in relation to a walking person may be an example. Essentially, the sensory mechanism in question seems

to determine the degree of coupling between the spatial velocity vectors of the moving elements. Shape and size constancy may be explained in terms of this mechanism (Johansson, 1964, 1975). The consecutive retinal images of moving objects then may be viewed as a geometrical transformation group.

7. A final word may be said about self-consciousness, which is often confused with consciousness as such. Any organism must be able to make a distinction between itself and its environment. Higher organisms have developed the ability to create an internal cognitive representation of themselves *in toto.* Probably there exist different levels of this ability. A cat or dog may react to their mirror image as a signal which indicates the presence of another animal, while at least humans recognize the image as a symbol, representing themselves. Humans also have an abstract awareness of being aware. This seems to be the essence of Descarte's dictum "cogito, ergo sum".

This short treatment of conscious information processing has shown

* some of the given prerequisites on which an active control and handling of information must rely,
* the restrictions which any given mechanism by necessity imposes on the system,
* the fact that these mechanisms nevertheless are the result of a long lasting adaptive evolution, which ensures an optimal[3] choice and retrieval of information from the environment.

5. Conscious reconstruction of external reality : intentional order and creative thought.

The brain performs some essential tasks :

1. The mapping and reconstruction of external reality in terms of cognitive constructs, which means the creation of internal order.
2. The extension of this order by an active manipulation of thought objects and the creation of entirely new concepts.

3. The interpretation of information and storage in memory as knowledge.
4. The intentional control of behaviour,aiming at a manipulation of the organism's physical environment.

These processes are not independent and pose some profound problems.

As early as 1949,the Cambridge psychologist Kenneth Craik made the assumption that perception means the creation of a model about our world, presupposing the cathegories of space and time (Craik, 1967; Blakemore, 1977). Cognitive constructs are based on a process of reconstruction where lost or otherwise missing sensory information may be regained in a hypothetical way. This demands the access to earlier stored knowledge. If the available sensory information is insufficient, the reconstruction may gain features of an illusion. There are essentially three levels of knowledge (the German word Erkenntnis (insight into) would have been more appropriate here). The process which leads to perceptual knowledge is generally unconscious, uncritical and non-revisable, but the result is instead visualizeable. The brain, however, has the ability to transcend these limitations stepwise. One crucial ability is the handling and transformation of mental objects. One may imagine the movement or rotation of a thought object in mental space. This task can essentially be simulated by a computer which controls the visual display of an object on a monitor screen. In a similar way knowledge by experience is created and mediated with the aid of concept formation, language and logic. This process is consciously controlled, but still uncritical. Scientific knowledge, finally, is based on highly abstract and formalized models (atoms, quarks, the particle-wave dualism, neutron stars, black holes etc.); the process of construction is critical, but its results are often no longer visualizeable. (Vollmer, 1982, 1984).

The working principles of the brain seems to demand a random access memory with unique features. Recognition of visual patterns, for example faces, occurs very rapidly and demands the simultaneous comparison of a very large number of stored "templates" (Lindsay & Norman, 1973). Experimental results (e.g. Lashley, 1960) seem to indicate a non-locality or very diffuse localization of the memory content. Furthermore, there is the demand for a very high capacity of the memory within a limited space. These features promoted the idea of a "holographic memory", which essentially constitutes an analogon to three-dimensional optical holograms (Pribram, 1966, 1969, 1971, 1981). While the basic elements of the stored information (including some indices of their order) must be very stable, there also has to exist a random access to minor or major blocks of them, since this is necessary for a recombination of elements. This promotes the idea of a hierarchical order of memory content.

By means of a Fourier transform, sensory messages can be expressed in a way which makes them compatible with a holographic memory. There exist some observations which support this assumption. The ear is normally able to recognize the composition of complex sounds in terms of their harmonic components, which essentially amounts to a Fourier analysis. This performance of the ear enables us to perceive polyphonic music.[4]

The discovery that the retina contains a large number of so called receptive fields, each one related to a set of higher order neurons, gave a clue to the functional architecture of the visual cortex (cp. Hubel, 1963; Hubel & Wiesel, 1979). The partial overlapping of receptive fields (using common receptor elements) illustrates the parsimony of the system. Receptive fields which are related to cortical neurons or modules, react to the presence on the retina of linear stimuli (bars or edges) with "correct" orientation. Hence, this mechanism was initially interpreted as a line-orientation detector. But it was shown later on, that cortical neurons cannot be classified with respect to single properties, and that their receptive fields represent transfer functions which express multiple feature selectivities (Lassonde et al., 1981). DeValois has earlier proposed a multi-channel spatial filter model, where retinal fields of different orientation are regarded as narrow windows to the external world. The mechanism essentially may be viewed as a set of spatial frequency filters which perform a total Fourier analysis across strips of the visual world (DeValois, 1980).

The multi-levelled intricacy of human memory may be illustrated by the phenomenon of multiple personality. During certain phases of her life, a person may show quite different personalities, comparable to a naturally occurring "Dr. Jekyl-Mr. Hyde" syndrome. This implies that complete programs have to be stored in memory, which represent the different personalities, but which probably utilize common subprograms and memory elements. The actual emergence of these specific patterns of behaviour, which constitute the "personalities", seems to be state-dependent. While both sets of programs are stored in the same substrate, they are only activated under appropriate states. The fact that one "personality" is not even aware of the other gives an extra dimension to the relationship between memory and conscious experience (Hilgard, 1977).

Another tough problem is the fact that the internal kind of order is not necessarily identical with the external one. This problem was already stated nearly 35 years ago by Friedrich v. Hayek in a very profound analysis of the subject. The author distinguishes between

"1. the physical order of the external world.....

2. the neural order of fibers and impulses proceeding in these fibers.....

3. the mental or phenomenal order of sensations (and other mental qualities), directly known although our knowledge is largely a "knowing how" and not a "knowing what".....

Our problem is determinated partly by the fact that the first and third of these orders are not isomorphous". (v. Hayek, 1952).

The author recognizes that one main problem regards the multiple classification of the external world in terms of single subjective experiences.

In fact, one should note, that there exist correlations between neurophysiological brain states[5] and mental events, but only weak or partial correlations between physical stimuli and experiences (notwithstanding very simple cases).One may illustrate this by the fact that "colour stimuli" are defined in terms of quantitative properties of light (wavelength or photon energy), while colour experiences are purely subjective phenomena, which are described in terms of qualitative features. The equivalent could be said about pitch discrimination of auditory stimuli. Colours are not properties of the physical world and there is no one-to-one relationship between physical stimuli and their conscious representation. (For details see Löwenhard, 1981,1984).

This leads to the meaning of the concept information. Some of the problem has already been touched upon in connection with the "degradation" of information which occurs at the synaptic junctions.

Heelan (1983) points out that one has to make a distinction between "information (1)" in the technical sense of Shannon's theory and "information (2)" which corresponds to a communicated content about the world. A stimulus really conveys a dual system "Info (1) + Info(2)". The whole problem arises,of course,due to the fact that the brain has access to two partly different sources of information:

* One is represented by recordings of electrophysiological or biochemical brain states (a subject may record its own electroencephalogram (EEG)).
* The other one is related to the earlier mentioned autoanalytical principle, which allows for experimental introspections.

Heelan gives a good illustration of this dual information in the construction of an elaborated model about visual perception. The author shows that perceived visual space may be described in terms of a hyperbolic (non-Euclidean) metric space, which by means of specific transformation laws is linked to physical space (in terms of Cartesia's coordinates). The model explains in a natural way a majority of visual illusions and other optical phenomena, related to the eye.

The nature of "information (2)" is somehow related to "meaning", which term has both cognitive and emotional aspects. The cognitive aspect has to do with recognition, the ability to identify a pattern as a known symbol. The emotional aspect has to do with an experience of something familiar, essential or imprtant, independent of the cognitive content of the symbol(s). It defines the subjective difference between signals and noise. Warren Weaver speaks of three levels of communication problems. The first level is related to the technical problem of how accurately a message is transmitted. The second level deals with the semantic problem how accurately the transmitted symbols convey the desired meaning. The third level, finally, deals with the problem of efficiency : how effective does the received message change the conduct? The first level, however, overlaps the second and third ones, which means that the technical theory significantly influences any higher level theory (Shannon & Weaver, 1959).

Hofstadter (1979) makes a different approach in his conception of "the three layers of a message":

1. The frame message evokes the recognition that a set of (non-random) symbols may represent a message ; also,there may be the need of a "decoding mechanism".
2. The outer message gives the necessary information about "how to build the correct decoding mechanism" or where aids to decipher the message can be found. An example would be the recognition of the language in which the message is written.
3. The inner message, finally, represents the meaning which the sender intended to convey.

An aspect of brain functions which as yet defies a detailed analysis, is the phenomenon of "intention" or "will". In a general physiological sense, the terms are used to denote the initiation of nerve activity which controls striate muscles and causes "voluntary" movements.

At the level of the CNS, however, the problem is similar to the one which lies behind the notions of the "self" or the "ego". In essence, "intention" denotes the experiental correlate to brain processes which start a controlled and guided nerve activity. But what exerts the control? What is controlled? Part of the answer lies in the functional hierarchy of the brain, but another part lies in the reflexive nature of consciousness. Conscious brain processes are not only characterized by the ability of the participating nerve nets to "recognize" their own states, but these processes work as organizing agents which are controlled by the information content of the ongoing process.

An "act of will" comprises a complex chain of events, both internal ones and observable actions.

* The formation of a program (thought process) which works as an internal prototype (model) of the intended action.
* The formation of executive master programs, which in turn use numbers of well established subroutines.
* The more or less conscious decision to start the execution of the program.
* The actual initiation of the chain of actions.
* Continuous control and supervision of the performance through sensory feedback and comparison of the real actions with the internal model program.

Alexander Luria (1970) has given a very elaborated model of the functional organization of our brain with respect to the different levels of its hierarchy.

In all probability the human brain has changed very little since the stone age, which means that essentially we have a brain which is very similar to that

of the stone age, 10,000 years ago. The difference lies in our factual knowlegde about the world. One may speculate whether or not a phylogenetic "hardware" evolution" of the nervous system has been succeeded by an acceleratd "software" evolution after a critical stage of phylogenetic evolution had been reached.
The complexity and plasticity of the brain as a physiological system makes, however, any distinction between "software" and "hardware" rather subtle. The exists an interesting reciprocal feedback process between the brain and its environment. In a sense one may view the brain as a universal Turing machine, i.e. a machine which is able to simulate the functions of any other machine. Programs may in this context be viewed as virtual machines. Their actions primarily result in cognitive constructs which, with the aid of directly controlled tools (arms, hands legs, feet), are then "transformed" into physical constructs (artifacts, physical tools, machines). As known, this process has resulted in substantial changes of our environment, which in turn has created the preconditions for the evolvement and realization of new ideas, inventions and discoveries.

One can thus recognize certain levels of development of human technology. The first one is related to force: manpower, means of transportation, tools, simple machines. The next level is determined by the availability of energy and raw materials: the search for new materials, more advanced and sophisticated machines, new sources of energy, miniaturization and growing amphasis on security. The third level is characterized by entropy (or information). Systems and states of higher order become more important than an increased range of technology. Key concepts are synergetics, bionics, automatic control. Systems of this type show a dynamics of their own. Their demand is on intellectual rather than manual skill or muscular strength (Schopper, 1982). This development has radically changed man's relation to his own technology.

At the dawn of civilization, the pre-stages of this process started when questions were asked by magicians, priests and scientists alike. They all aimed at an understanding of the rules of nature in order to predict future events and to control the environment. Science slowly has adapted its models according to the growing knowledge and empirical evidence, while magicians tried to impose their thought models onto nature. The difference reveals itself in the continuously increasing efficiency of science : it works.

Some years ago, Abdus Salam, Nobel Laureate in physics, gave an interesting illustration of the efficiency of scientific thinking. Durin a lecture given in Stockholm in 1975, he presented the following example: One may remind oneself that 300 years ago, about 1660, two of the greatest monuments in modern history were created, one in a western country, the other in an eastern. I am speaking of St. Paul's Cathedral in London and The Tai Mahal in Agra. Both symbolize better than words, the comparable level of craftmanship, art and sophistication that both cultures had reached at this epoch of history. At the same time, however, a third monument was created, and this time only in the west - a monument whose importance to mankind should be still more overwhelming : Newton's "Principia", published in 1687. Newton's great work had no equivalent in the India of Moguls. Salam pointed out that this difference has only existed for about 300 years, but it gave rise to the rapid development of western civilization, built on its mastering of the rules of nature. This development,in turn,created the broadening gulf between industrialized and "underdeveloped" countries with respect to technological standard (c.fr. Pietschmann, 1980). There are, of course, other factors which contribute to this result, such as economical and cultural circumstances. Some of them will be treated in the contributions of Dr. Radnitzky and Dr. Ayres.

The future development and destiny of mankind, however,is crucially linked to those brain functions which have been the topic of this paper.

N O T E S

1. (p. 18) The concept of hierarchical level is difficult to define strictly in a general sense (see e.g. Bunge, 1973, Kanitscheider, 1974). Here the term refers to a functional system of receptors, mediating neural pathways and analyzing nerve nets. The final stage, storage of information in memory, is still an open question, since the physiological basis of memory is not known in detail (cp. John, 1968).
2. (p. 23) The term negentropic flexibility is coined Sayre : "In speaking of flexibility in the assimilation of negentropy I refer to the capacity of an organism to establish efficient couplings with its environment under a range of different conditions, through which negentropy can be obtained to support growth and metabolism and to control its response to environmental contingencies" (Sayre, 1976, p. 117).
3. (p. 27) the term "optimal" here means that the organism fits to its environment
   1. as to its ability to utilize a choice of sources of information which are most pertinent to the ecological role of the organism and
   2. to use these sources with a high efficiency. An example would be the close correspondence between the spectral sensitivity curve of the human eye during photopic vision and the spectral intensity distribution of the sunlight.

The brain is mainly an instrument for survival. Its capacity and way of information processing are determined by the needs of the particular organism to which it belongs. The behavioural repertoire of phylogenetically lower organisms (such as invertebrates) is to a high extent predetermined. This includes the structure of their nervous systems and their way to retrieve and process information. During the course of phylogenetic evolution there have been changes alongside the development of new species. Meanwhile, basic properties of the nervous system must have been preserved during evolution. Simple and complex nervous systems alike show, for example, both short term and long term habituation, i.e. the ability to learn and to modify behaviour (Kandel, 1979). The evolution of new species often implies the emergence of new modes of behaviour. This demands a change of existing brain structures or the development of new ones. In order to adapt and to increase its behavioural efficiency the organism may be dependent on new types of stimuli and an increased range of information, which has to be processed appropriately. New additional brain functions, however, brings about an increased specialization ("division of labour") and a more complex organization (Luria, 1970).

Nature seems to preserve successful stages of evolution. One therefore finds a superposition of phylogenetically newer structures on older ones. A model of this import has been proposed by McLean (1973) in his Triune concept of the brain. From the very basic structures of the spinal cord and medulla oblongata, the R-complex (reptile complex) has evolved stepwise. Its main functions are related to the survival of the species and the individual (reproduction, struggle for the establishment of a social hierarchy). The R-complex has been supposed to be the brain of the dinosaurs , but it is still a part of our own "ancient" brain, however, modified. Reproduction as one of the main characteristics of living organisms may illustrate some steps of evolution. Reptiles lay eggs which then are hatched by the sun. Birds lay also eggs, but they sit on them and feed their offspring. This more extensive caretaking demanded new brain structures and appropriate programs. Both are related to the "new" structures of the limbic system (rhinencephalon). Carl Sagan, in his charming epic "The dragons of Eden" (1978), makes the remark that the development of the limbic system meant the birth of altruism. Mammals, finally, give birth to living offsprings, which demands a still more complex repertoire of caretaking. Mammals then are dominated by the neocortex, the complex "new brain". Nevertheless, all the earlier structures remain; what has changed is their relative dominance and the details of their functions. They have become part of a more complex, integrated brain.

4. (p. 29) In a sense the eye and the ear work in opposite ways. While the visual mechanism integrates a composite stimulus into a single perception (a mixture of light is perceived as a single colour), the auditory mechanism analyzes a complex sound with respect to its harmonic components. Two or more different sound stimuli are perceived separately (notwithstanding certain exceptions such as human speech). This fact is known as Ohm's Acoustic Law.
5. (p. 31) Neurophysiological brain states may be defined in terms of specific patterns of electric and metabolic activities in brain structures, which consistently participate in a given type of experience or mental event. Technically the information which indicates a certain brain state may be obtained from an analysis of EEG recordings and the selective distribution of blood flow, indicating local metabolic activities. Detailed correlates are only known in certain specific cases.

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E R R A T A

p. 3, row 5 from below ...... of different (missing)

p. 6, row 10 from below Zeirgeist should be Zeitgeist

p. 14, row 11 concersion should be conversion

p. 20, row 7 related to consciousness

p. 23, row 3 from below barin should be brain

p. 25, row 4 manifestation should be manifestations

p. 27, row 9 from below .....adaptive evolution should be adaptive and organizational evolution

p. 32, row 3 Cartesia's should be Cartesian

p. 34, row 3 acceleratd should be accelerated

p. 35, row 9 durin should be during