Impact of information compression on intellectual activities in the brain

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"What is...is identical with the thought that recognizes it"
- Parmenides of Elea, ca. 480 BC[1]

Imaging and modelling represent an action of information compression, which is inevitable for a complex system in order to process and communicate data. Humans are such complex systems. Sensory and body reaction information is processed by the brain, the overall information rate being 10^{11}-10^{12} bit/s. Consciousness is the result of massive information compression, the attentional data rate being 10-14 bit/s. The primary purpose of the conscious state is to control the interaction with the environment. In humans, this ability facilitates the projection of the future horizon far away from the next instant. Thinking and reasoning can be thought of as a process of retrospective control. Retrospective in the sense that the subconscious has already decided what is to come next. In the long run, however, conscious thought influences the cortical context potentiation, thus providing steering to the associative process. The paper emphasizes that all cognitive operations are restricted to the bioelectrical signal processing in the brain. Accordingly, mental models and scientific theories will always be constrained by this fact. The last subject of this paper deals with the interaction between the brain, the glands and the rest of the body. It is interpreted that qualia are the result of a complex feedback interaction between those parts, a self-supported process close to a singularity point.

1. Scope and objectives

All biologic organisms form complex systems wherein millions of internal functions strive towards a simple output. By simplicity we refer to the amount of information needed to perform a certain action as compared to the information used in the internal processes. The primary outputs aim at securing the continuity of the organism by self-preservation and reproduction. In this paper we attempt to present a holistic model of the information interplay between on one hand a human being and the environment and on the other hand brain centers and the rest of the body. Due to natural selection the hierarchial structure of information flow is brought to optimal rationality, meaning that subsystems are controlled partly by internal signals and partly by communicated information. This can be considered as a general feature of a complex system, namely that subsystems of partial independence form a resource flow network while coordination and coherence is provided by an information network. Hence it is natural to consider biological systems as fundamental study objects for complexity. On the other hand, universal regularities of emergent self-organizing physical systems can be applied to living entireties.

One main interest of this paper will be to consider the human being as a part of a community. Why is he or she acting in accordance with social agreements? What is the minimum information exchange needed? Which are the internal mental requirements for a successful interplay? These are questions we try to tackle. Simultaneously we will touch some of the most intriguing issues of the human mind, consciousness, intentionality and self-awareness.

What purpose do these characteristics have? - presently a mainstream question, to which we will not find a commonly accepted answer. Here, however, we shall pragmatically claim that consciousness is a continuous process of displaying strategies for action. The comparison to virtual reality simulation is very tempting, but the process is far more complicated than running a computer model in order to look into a future scenario. Consciousness is the result of a massive compression of information wherein incoming sensory signals alert different centers by creating recognition patterns of objects through vision, sound, smelling, feeling or whatever the stimulation might be. The primary purpose is to control action or rather, reaction. This ability has, due to the development, reached a very high level in humans facilitating the transfer of the *future horizon* far away from the next instant.

Intentionality can be characterized as an agenda for "keep going". That is an inbuilt *arrow of action*, which helps to maintain conscious continuity, but which also prevents the individual from reaching equilibrium, ever. This has also to do with the self-organizing process of thinking always taking place in the brain.

Self-awareness brings us close to the virtual reality scenario. By self-awareness we are able to observe ourselves as objects in different imaginative situations. Remembering means time travelling backwards, while planning the next vacation transfers us several months ahead in time. Self-awareness has to do with the human ability to operate consciousness with the assistance of concepts, which in themselves are compressed information of miscellaneous entireties.

The last point to be considered is that human beings form very complex systems comprising both bioelectrical and biochemical signalling for internal communication. The brain, the body and the body glands exhibit a wholeness that is provided with a multitude of interconnected feedback loops. The over all behavior of the individual will be synergetic to it's character meaning that there is no analytic algorithm describing the relation between inputs and behavior. Instead initial sensory signals will always be confronted with a new system, the behavior of which depends critically on the previous state and the emergent trajectories of brain functions. Internally the feedback loops between brain, glands, heart, lungs etc. form an undisconnectable entirety as long as we talk about a living creature. These loops are most probably responsible for "non-computational" features such as emotions and pain.

2. Complexity

2.1 Information

The word "information" has a very wide use, often it is the substitute for "signal" or "data" or just a common message. Strictly interpreted information refers to the part of a message that is new to the receiver and that accordingly causes a reaction. Without a reaction it will only be new memory data. However, it has been extremely difficult to define the minimum information needed for a certain message to be correctly interpreted in the receivers end. Considering disturbances in the transmission link there is always an uncertainty related to the process.

Complex systems are based on information exchange. Without the communication between individual parts connectivity and self-organization would never emerge. By fine-tuning the necessary flow of information a system is able to undergo a continuous development and to oppose the growth of entropy. It is also flexible to outer changes, provided these are not catastrophic to their character. A catastrophe means that some input signal or some boundary condition changes too much too fast.

It is typical for a sophisticated complex system that the exchange information is coded in a way to maximize the capacity of the channels. The receiver utilizes as much memory data as possible. Todays coding in signal processing and telecommunication aims at a transmission of a complete representation of a certain message, e.g. a time dependent visual image. For comparison in oral communication between, say, a lecturer and an audience, the word "sex" (approximately 6 bit) generates myriads of bits in the form of more or less emotional experiences in each listener capturing a lot of individual flavours. Future multimedia and virtual reality communication will be based on the transmission of solely new information. Context and background patterns will be locally stored and provided on request in the receiving end.

2.2 Information depth

In order to get a quantitive grip of the value of information several attempts have been made to define the the measure of "depth". Kolmogorov[3] tried to use the shortest string of information required to explain a phenomenon. But there is always many possibilities to shorten the string by using different algorithms, i.e. by compressing some of the information in, say, an equation. Charles Bennet[4] has investigated how much information is rejected during a process of compression by complexification. He coined the term "logical depth". Anyhow, there are many uncertainty factors related to the concept of information, accordingly one should consider all situations where information has to be interpreted as statistical ones.

In this paper we are interested in the compression of messages communicated between human beings. Our concern is: what is the shortest message, say M bit, to be transmitted in order to achieve the highest possible intended recognition among a certain population. For this purpose we can define a measure *perceptional depth*

$$D = (M \cdot H)^{-1} \qquad (1)$$

where H is the Shannon information entropy function according to

$$H = - \Sigma\, p_i \log p_i \qquad (2)$$

The interpretation of H depends on the specific case. Let me illuminate it's definition with two examples. A culturally homogeneous population is asked to list, say 5 composers, the question being of the form "famous composers?" (c:a 32 bit, avaraging 2 bit per letter due to redundancy). One could use only "composers?" (20 bit), then adding more uncertainity, or specify "famous classic composers?" (50 bit). The answers result in certain distribution among, say, 20 (N) composer names. The factor p_i (i = 1...N) indicates the probability for certain composer to get a vote, i.e. the ratio of the individual number of votes and the total number of votes. Complete concensus (all votes for Beethoven, N = i = 1, p_i = 1) means infinite depth (H = 0).

The interpretation of this definition is that the most valuable situation for the sender of a message is such, that a majority of the receivers draw the right conclusions. A low perception depth value would indicate that very few people understood the meaning of a communicated concept. This measure could be used to penetrate the education level of a certain society or the mixing of two cultures.

The second example is related to pattern recognition by artificial neural networks (ANN). Take an input vector $\mathbf{X}$, let $\mathbf{W}_i$ denote the set of weighting factors connecting $\mathbf{X}$ to the output vector $\mathbf{Y}_i$, Figure 1. Because $\mathbf{W}_i$ is determined according to an optimization algorithm, very small discrepancies in the input $\mathbf{X}$ cause different recognition interpretations, i.e. alterations in $\mathbf{W}_i$. Let $p(\mathbf{W}_i)$ denote the probability that an input $\mathbf{X}$ results in the set $\mathbf{W}_i$. By letting M stand for the information content of $\mathbf{X}$ and using statistical experimental data for $p(\mathbf{W}_i)$, we can calculate D according to equations (1) and (2). The result can be used for the evaluation of a specific neural network architecture.

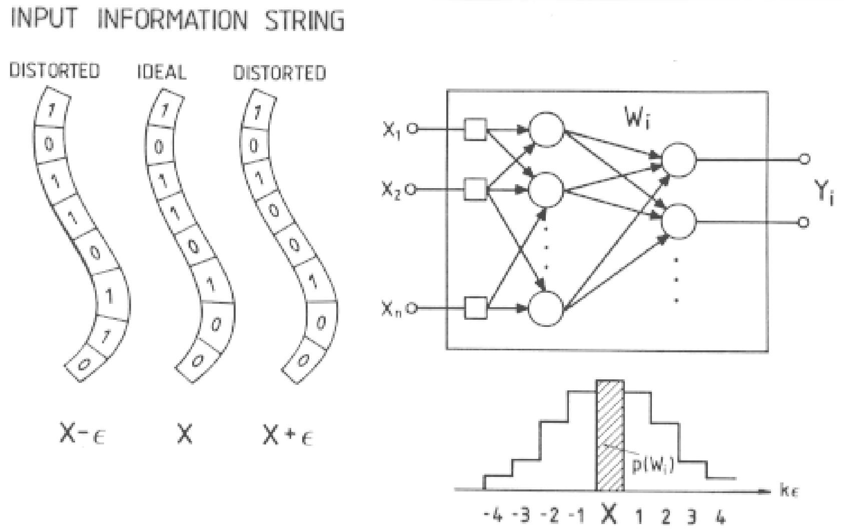

Figure 1. Schematic representation of the probability of pattern recognition. The input **X** results with a certain probability $p_k(\mathbf{W}_i)$ in pattern $\mathbf{Y}_i$. Distortions in **X** decreases the probability.

Although the perception depth might have little practical use, the previous examples hopefully serve as metaphors of the sensitivity of pattern recognition. Small noise factors on the input side can lead to completely different interpretations. This is one component for chaos in the brain. It also emphasizes the non-deterministic character of identification by neural computing. In unchanged "laboratory conditions" comprising identical input signals in subsequent experiments and stable hardware (ANN) the outputs should be deterministic. In the real world, however, inputs are never the same and the recognition process in the brain is time and state dependent, meaning that previous states affect the outcome. If we add the idea that every recognition process follows an emergent self-organized agenda, we conclude that cognition never clings to an old track. It is the opinion of the present author that the seeds of non-deterministic, free-will, if one wants to, behaviour are to be found from these arguments. Erich Harth of Syracuse University advocates similar ideas in his book The Creative Loop[5].

2.3 Computation in the brain

Marvin Minsky once coined the saying "the brain is a computer made of meat". This somewhat provocative statement goes to the roots of one of the most intricate questions in the science of cognitivity. Namely, should mental processes be considered as computational? Part of the problem is that we as human beings are not objective enough to say YES. Traditions, emotional involvement, religious relicts, etc. prevent us from confessing that complicated signal processing is taking place in our heads. Things like "mind" and "self" enhance the confusion. But the facts are that cognition requires neurons firing electrochemical signals, i.e. processing information, and specialized brain centres, of which the cortex is necessary for reasoning and predictive thought functions. Even minor tissue damage reflects deviations from what is usually considered as normal behaviour.

However, computation in the brain is quite different from computing in a technical sense. There is no stored program controlling signal paths. The algorithm is a built-in feature of the network structure. A cognitive task progresses through thousands of parallel, locationally distributed subcenter networks. Artificial neural networks of today aim at imitating their biological counterparts. Working as identifiers or classifiers they come rather close, but functionally they are still very primitive. Artificial nets need strong computational support in performing procedures of optimization, back-propagation, etc. How the brain handle these functions is not clear, but it seems reasonable to think that a self-organized emergent progression takes place on a very short time scale. Thus bioelectrical actions repeat in milliseconds what is biochemically going on on the million year time scale.

Finally, I will give some attention to modelling and simulation. A model is never the real thing. It is a representation utilizing different media to store information. The purpose of a model is to confine certain features of interest. Examples range from simple mathematical equations and numerical strings of information to sophisticated robotic models of living creatures. Simulation means performing experiments on models[6].

One must always be aware of the fact that in the attempt to create an understanding of a complex phenomenon, e.g. global finance or Theory of Everything, the modelling process in the brain is confined to bioelectric signals and the neural network structure. If the phenomenon does not provide computable features meeting these constraints, an understandable description is not at hand.

3. The purpose of consciousness

3.1 Difficulties to define consciousness

Consciousness exhibits too many features to be fitted into a holistic description. As long as the physiological background of neural processes is incomplete, it is hard to believe that a satisfactory theory will appear. Several philosophers on the subject have tried to define a site for consciousness[5,7]. Although multiple cortex centres, assisted by the limbic system and the brain stem, are involved in a conscious process, one tend to expect that the summarizing stream of information must meet in a specific organ in order to provide awareness. Thalamus is a strong candidate, because it serves as the relay station of neuronal signals. However, we will not spend more time on this question, instead we shall recollect some relevant features.

It is typical for biologic neural signal processing - which has to do with the ultimate rationality of natural selection - to focus on a small source of information and on the same time develop or maintain a larger area of dimmer information. This is how the eye works. Consciousness can be characterized by a focus, i.e. attention, and a surrounding area of awareness. The awareness is not directly connected to the attentional focus, it rather depends on the context currently backing or illuminating the focus. However, from experience we know that signals from the awareness area try to catch the attention, thus providing steering on conscious progression. Awareness then reflects the competition taking place in the subconscious as a part of the information compression process.

Consciousness is normally an uninterrupted process that maintain a certain level of alertness despite different stages of rest (sleeping modes). The contrast with unconsciousness is very clear, even the influence of drugs on conscious behaviour is easily registered.

3.2 Cognition by recognition - how consciousness works

In this paragraph I will emphasize two hypothetical principles, namely, that all sensory signals must be recognized before entering consciousness and that thinking and reasoning are simulation processes aiming at the preservation of continuity.

As Parmenides deduced around 480 BC and John A. Wheeler later has focused on, "what is", i.e. reality, " is identical with the thought that recognizes it". German philosopher Immanuel Kant (1724-1804) emphasized in the late 18th century that sensory impressions pass through a process of apprehension, reproduction and recognition before reaching awareness. So, in order to recognize the reality of his surrounding an intelligent being has to find the equivalent representation from his memory. This is also the standard agenda for pattern recognition. In the attempts to characterize consciousness a metaphoric comparison to computer simulation has been promoted by several authors[8,9,10]. In short we can say that consciousness is a continuous result display of reality simulations, in which process impulses of recognized sensory (vision, auditory, etc.) signals synchronized the "computational" output with reality. The simulation generates a surge of associative initiatives, which follow the conscious focus trajectory as a spatial information tube (awareness) ready to provide new directions for the focus line on the request of sensory information. A naive representation of these functions is shown in Figure 2. The

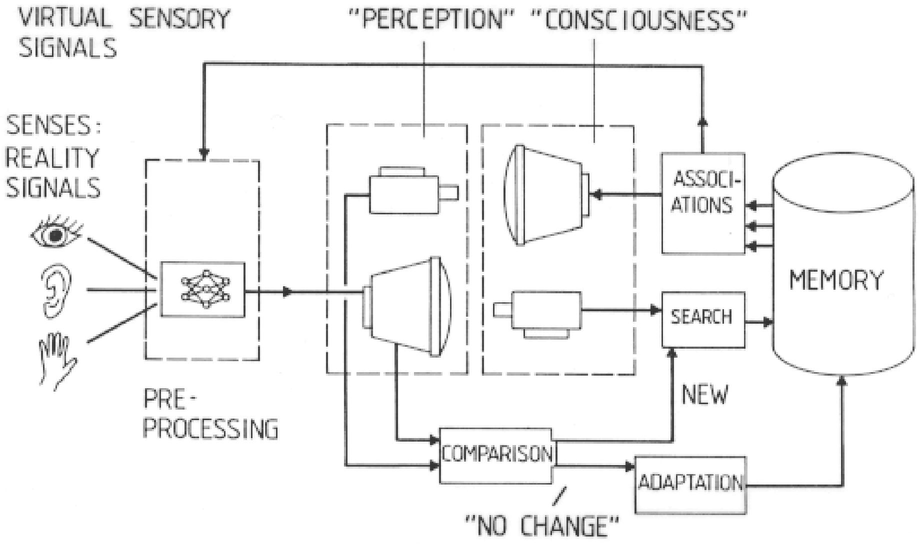

Figure 2. A naive diagram showing the principle of pattern recognition by image comparison (massive information) and the generation of associative incentives working as virtual sensory input signals. Here "perception" means subconsciously received, but not consciously identified.

counter-connected monitors and videocameras symbolize the simultaneous processing of millions of bits. Different estimations suggest that the conscious focus information stream is of the order 20...40 bit/s, while for instance visional input is 10^7 bit/s and the cognitive process involved in the interaction operates $10^{10}...10^{11}$ bit/s[11].

The virtual reality model is convenient in several senses, e.g. it provides a tool to discuss - and demystify - the interpretations of Benjamin Libets results of the timing of sensory and cortical stimuli[12]. Further the model allows the mind to move freely in time and space during associative "free-wheeling", i.e. thinking, reasoning, dreaming, etc. However, as for all metaphors, one has to be cautious with the interpretations, the brain is not a computer in the normal sense that perform sequential logic operations according to a given algorithm. Simulation in the brain is based on massive neural feedback processes, an instant awareness pattern associates to the next and so on in an infinite chain. The neural networks of the brain do not compute weight factors. Actually, they do not perform algebraic computations at all. Externally excited mathematical operations follow learned patterns, we simply recollect that two plus two equals four or seven times eleven is seventy seven. We still know very little about the dynamic operation of the brain. "Programming" is a self-organized generic process, which would be very useful to understand. Artificial pattern recognition and neural computing require time consuming optimization, the brain sorts out the essential information of a visual sensation in 300 ms compressing an information stream of 10 million bit/s to 40 bit/s.

3.3 Linguistic compression

Verbal communication between two persons is based on extremely effective compression. The speaker and the listener ought to have the more cultural "fitness" the deeper the conversation penetrates a specific subject. Here the words really works as the synchronization impulses for individual virtual reality simulations. Figure 3 illustrates how a visual experience is mediated verbally by "me" to a second person, "you". The scale to the left indicates the order of magnitude of information involved at each stage. As pointed out before, the conscious thought and verbal message operate very little information. A precise interpretation requires a rich language and generally accepted semantics. The development of consciousness and especially the the extent of the awareness region is probably closely connected to the emerge of a spoken language. Words create context entireties in the subconscious, accordingly enhancing the ability to confine large information quantities during reasoning or developing an understanding for a complex phenomenon. Words are not only the unit blocks of communication, they also "transport" information between the subconscious and awareness. In conclusion we can establish that verbal communication has led to extended awareness and the emergence of meaning, i.e. informational depth.

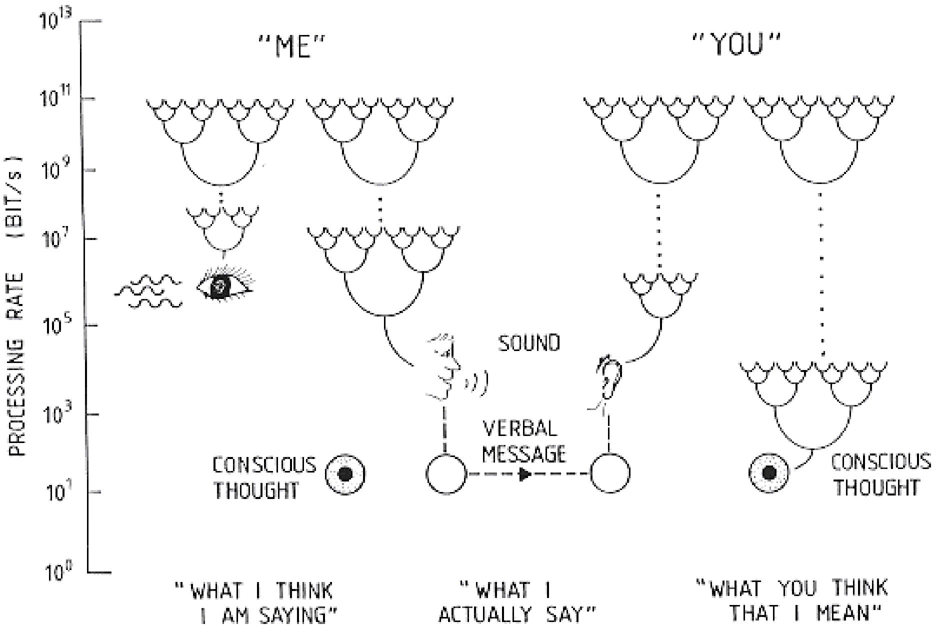

Figure 3. The stream if information at different levels of cortical activation. As an example the me-person verbally informs the you-person what he is seeing.

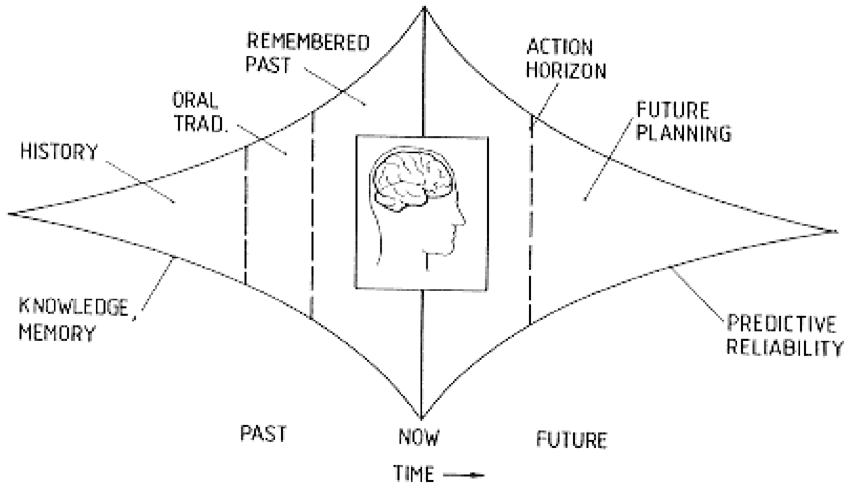

Figure 4. The "time travelling" space of the human mind.

3.4 Self-awareness

If the language made it possible to consciously handle larger amounts of information it also speeded up the processing, maybe created the pre-requisites for reasoning. At some point, either through a gradual or a transitional process, reasoning changed to a virtual reality type operation, wherein the subject suddenly takes the role of an outside observer, the self. This finally liberated the individual from confinement to real time, he saw himself as an actor in the model representation. Figure 4 shows schematically how extended awareness combined with knowledge facilitates the transference of the future horizon ever further away from the present.

4. Pain, pleasure and intentionality

4.1 The Turing rational actor model

The extended Turing machine[13] is shown in Figure 5. Here the analyser/synthesizer is assumed to correspond to the conventional Turing machine. The left figure roughly indicates the equivalence between a biological being and the model. The receptors do all kinds of sensing while the effectors act on the analysers command. Effectors are not only arms and legs, but hypothalamus, heart, lungs and digestion system as well. Effectors are supervised by the autonomic and the somatic nervous system, represented by the direct arrow to the receptor in the figure. Effectors also influence the body glands, e.g. due to exertion. The whole system is in a strong interaction with the environment. Biologically the being is living on the terms of the surrounding or more precisely, natural selection has dictated the development of "actor" complexity.

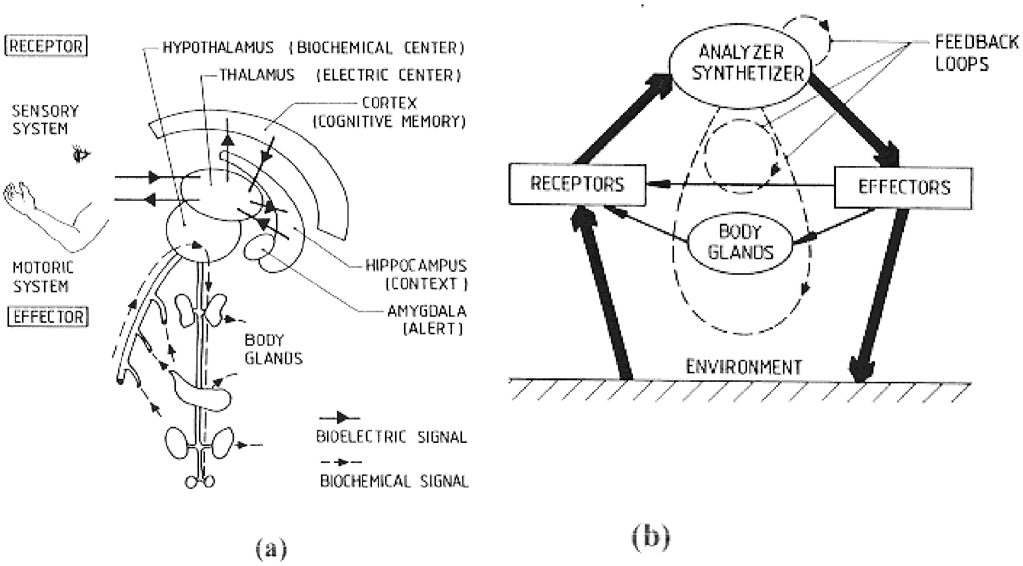

Figure 5. The Turing rational actor model. (a) Schematic representation of the main signal systems of the body. (b) Compressed model indicating interactions and feedback loops.

4.2 Impact of biochemical feedback

Figure 5 indicates many interactions, the controlling function of the "analyser" (brain) is governed by a multitude of feedback loops working on different time scales. Controlling movements by eye-following requires fast reactions. Even biochemical feedback via the glands can be very fast, take for instance the secretion of adrenaline in case of a threat or when a conversation rises emotions. Actually one reason for including this paragraph is the belief that emotions, pain, joy, hunger, sexual arousal etc. all are the result of a complicated interplay between the brain and the rest of the body. The secretion of hormones affects the context potentiation of the brain, thereby giving steering primarily to the subconscious and secondarily the conscious mind. It is impossible to think of a computer feeling pain or depression. These characteristics must be the result of a feedback process tending towards a singularity point, meaning that the feeling of pain, like other emotions, amplifies itself and inhibits awarding functions of the brain like the secretion of endorphins. In the opposite situation of joy or pleasure, the endorphins and equivalent mechanisms are enhanced. But these electro-biochemical actions are not enough to excite a state of partial or complete dominance on the individual. The interplay is reflected on the process of information compression in the subconscious, negative emotions seed virtual reality associations in a direction that enhances discomfort. Pleasant arousal in turn strengthen the emotional mood by awakening memories of similar experiences. Actually all these reactions are continuously present to a certain degree. They are part of the irreversible self-sustainable process of being a living creature.

The influence of the body's biochemical responses on context formation, primarily mediated by the limbic system, is even more important than the influence of incoming sensory information. The context is responsible for the potentiation of certain cortical centres and accordingly for controlling the recognition process and further for the compression of information towards consciousness. The state of the individual as a whole will have a great impact on associative directions and the virtual reality scenarios ran for predictive purposes. The "self" is most probably the product of these interactions. A superficially sustained brain, "brain in a bowl", will not provide consciousness, because it lacks biological input. In principle such functions can be simulated by an artificial "back-up" system.

4.3 Intentionality

In this paper the word "intentionality" should be interpreted in a broad sense, ranging from incentive motivation to long term future planning. The expression "arrow of action" underlines the character of dynamic continuation in all living beings. Temporarily sensory inputs provide stimulation for cognitive sustentation, but this kind of "computation" would once in a while come to a stop. There exists an inbuilt hierarchy of reference frames, which, depending on the current context, initiate associative thoughts or, internal virtual reality simulations, if we wish. The frames can be ranked according to the Maslow scheme[14] starting with short term needs as food and shelter and continuing with safety and affiliation (social needs). Needs for knowledge (cognitive), beauty (aesthetic) and self-actualization are topping the pyramid. The initiation of internal incentives starts from the lower levels and upon satisfaction continues towards higher values. One dominating ingredient in the intentional interplay is the "gradient of surprise", i.e. the need to mentally move towards unexplored grounds. This is clearly reflected by the tempting force of computer science and multimedia. In the intentional process both inherited behavioural and acquired ethical constraints have an important function.

5. Conclusions

The complexity of the Universe is characterized by self-similarity, order and organization. This fact facilitates modelling in as well mathematical as mental form. The human brain works with models utilizing neural networks and electrochemical signalling. The brain can only elaborate phenomena that provide enough patterns for modelling. The connection between reality and brain functions is established by pattern recognition. Consciousness is based on memory information triggered by sensory stimulation, the major part of conscious experiences being the result of a continuous associative process comparable to virtual reality simulation. Steering is partly provided by the sensory input, but mainly by cortical context potentiation, which depends on emotions and history factors.

Self-awareness may be considered as a slow transitional occasion in the history of natural selection. Linguistic information compression has caused a radical expansion of attentional awareness, thus facilitating the conscious mind to operate large amounts of information represented by "sparse" concepts. Imagination has freed the individual from the instant of reality, whereby the future horizon has been extended from the next movement to the planning of the day, the week or the rest of the life.

Issues presented in this paper must be considered in order to develop sophisticated artificial intelligence.

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