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## *THE TIME-MEMORY COMPLEX*

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Largely owing to the relativity theory, time as a physical concept has played an exciting role in the last half of this century. Less interest has been devoted to time in a biological context. Obviously, time is also a physical reality in the physiological experiment, say, in tracing the activity of a reflex pathway or in following the course of a chemical reaction. This may be called time as "hardware." But in these comments I am dealing with time manifesting itself in consciousness and intend to refer to it as "software." In this capacity, time has important creative functions, best known from the sensory domain. A good example is the vivid percept of velocity in vision. In acoustics, the whole tonal world is a temporal integration.

As software, time is at the disposal of the organism for the creation of novelty. Its major adjuvant in this task is memory. By definition memory is something that unfolds in a temporal dimension. One major property of memory is its duration. Neglect time by giving it zero value, and memory is gone. It is this connection between time and memory that the term time-memory complex is meant to emphasize.

In the physiological experiment, durability of a state of excitation or inhibition is assumed to be the basis of memory regarded as measurable hardware. This may well be true and as close to the physiology of remembering as we are likely to arrive. But the time-memory complex as it expresses itself in a software sequence contains more than the time course of a long-lasting measurable synaptic event. As a first example,

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consider the process of feature detection by a cell within the cortical projection of some sensory afferents. This concept itself is a hybrid between a software notion of a “feature” as perceived by a mind and a hardware experimental finding whose relevance is legitimized by the electrical response of a cell to which the feature is presented. The cell chooses between yes or no. In the background is the general idea of localization in the brain of software specifications.

There is, of course, a pure hardware notion of localization as, for instance, in the hunt for the site of the nucleus of the vagus nerve. However, the more interesting development in this context has concerned software-hardware relations as initiated in the 1860s by Broca’s discovery of the speech motor center. Recording from single cortical cells has added an element of analytical precision to this field of study.

If this development is considered from the point of view of formation of time-memory complexes, recording from a single cortical cell is merely the last memorized part of something begun in the periphery. Consider, for instance, the well-known Hubel and Wiesel discovery of visual cells in the striate area sensitive to the orientation of an object presented on a vertical screen that the animal is viewing. The time-memory complex has its roots in the receptive fields organized by the retinal center, it undergoes evaluation and transformation at the level of the geniculate body, and it is finally reorganized in the striate area where it is recorded. The directional sensitivity of the striate cell is thus the end result of an extended process of “editing” fixed by a sequential time-memory complex to its purposive end. In a wider sense, localization refers to this extensive structure and not merely to the final site at which the feature is being recorded. The timed subconscious memory is always likely to occupy more space and time than what reaches awareness. Time-memory complex as a concept covers both conscious and subconscious components of the whole sequence.

Sequential processes combining time and memory are the basis of everything we do, perceive, think, and so on. They are the neural structures behind our learning to walk, to talk, to anticipate, and to recollect—in short, to exist in this world. Dramatic illustrations of these statements may be had from successful operations on people born blind and suddenly being exposed to the world of light, form, and color. There are those among them who prefer to withdraw into their familiar past of tactual and acoustic living rather than to undertake the formidable task of organizing the necessary time-memory complexes so as to fit the perplexed inside to the new outside.

In such experiences, the purposiveness of our software conscious world demonstrates its grip on physical and chemical processes in our nervous system. The mind has, so to speak, grafted itself on available

nervous mechanisms, just as in the course of evolution the tongue in the end has become an instrument of speech.

There may well be cortical regions specifically devoted to the creation of purposive sequences combining time and memory. It is clearly a question of multicellular activity. Specific time cells or specific memory cells cannot be shown to exist. The decisive process in the establishing of sequences is one of organization. In this, time and memory are integrated for the creation of novelty. This may involve numerous sites and serve purposive adaptations to the environment. The role of the environment can be seen most clearly when an ingrained adaptation is proved to be faulty, as when a person is made to wear inverting spectacles. Readjustment to normality from upside-down vision may become virtually perfect within a couple of weeks. This has implied creation of new time-memory complexes. We do not understand how the conversion to normality has been established; clearly, it has taken place under the influence of severe confrontations with other sources of input. But the details of the reply to this “how question” escape us. We have to be content with the “why criterion” that the process is purposive with respect to the environment.

Replies to why questions belong to the category of teleological thinking that at one time was looked down on by respectable scientists. But now, when so many neuroscientists are engaged in the study of diverse adaptations, including the readaptations mentioned above, teleology may be said to have sneaked in by the back door, in passing giving rise to new branches of science, such as ethology.

Returning to the creative marriage between time and memory in complex sequences—what are the perspectives for a successful analysis of such processes as how problems? Let us recall that in the findings and conclusions so far presented, software time has appeared in two roles: (i) as duration of memory, and (ii) as member of an integration, the time-memory complex. In the first context it is within limits accessible also as hardware. It has been studied as duration of long-lasting synaptic facilitations, for instance, in the hippocampus and in the clam *Aplysia*. These results are highly important but refer, after all, merely to the first of the two roles put forth. The second implies an everyday experience such as our capacity to recall an event from our past in great detail in its correct sequential time. In a well-known experiment, Penfield succeeded in producing this result by electrical stimulation of the temporal lobe of a patient, thus demonstrating that this software experience had a physiological basis—hardly doubted by anyone. To put it differently: such familiar facts really signify that time can be remembered and retrieved provided that it has become part of a time-memory complex.

Why is time in its second role, as given by some examples in the

previous section, so difficult to analyze on the customary how basis of natural science? My reply is that science habitually proceeds by fragmentation of its material. The physicists have led the way into the microworld, and we biologists have been trying to follow close on their heels. Inasmuch as there are hardware elements behind the software time-memory complexes, they are bound to operate a number of cellular microevents. However, since the phenomenon to be explained is an organized synthesis carrying some meaning, little is gained by a “vertical” analysis down to the ultimate microlevel of the cellular processes behind it. The best we can do in hardware research is to record from individual cells and show that they synthesize specific responses to wavelength, tonal frequency, directional sensitivity, skin area, and so forth. Such cells are then assumed to be components in the detection of features, as previously discussed. Even combinations of “features” can be ascribed to individual cells.

But let us consider the percept of velocity of an object moving across the visual field. Confront this with the situation in which the same object passes across the retina as a consequence of an eye or head movement. In the first situation we perceive velocity, in the second we note that our environment is steady. Our creative brain has distinguished two purposive modes of response, taking into account the need for an organism to react to the rate of approach of danger as well as to be adjusted for a life in stable surroundings. There is at least one well-analyzed case of loss of the percept of velocity; Gelb and Goldstein’s patient from the First World War, shot through the head and seeing the tram only in successive positions but not the movement as velocity. It is quite possible to trace the movement of an image across the retina. But in this hardware experiment we are in the situation of Gelb and Goldstein’s patient!

As another example: consider a sequence expressed by a sentence. It can easily be split into millisecond events but to no avail, since the significant fact is that the sentence conveys a meaning and so fragmentation has become irrelevant. The same holds good for a single word, say, the word “understanding.” As a first attempt at analysis it can be split into “un-der-stan-ding.” In the end one could reach phonemic understanding but not the insight that is its software meaning. It is commonly—and quite rightly—maintained that the whole is more than its parts, but this statement does not add much to our understanding of the mind’s creative operations. At the moment teleological interpretations, whenever they can be sensibly applied, are our safest avenue to insight in the software world, and insight is, of course, what science is aiming at.

To some the introduction of a concept such as the “time-memory complex” may seem empirically useless. They would regard it as “gray theory” with no connection to “life’s golden tree.” This attitude is easily refuted by reference to a considerable clinical literature based on obser-

vations by psychiatrists. Time problems in psychiatry have recently been discussed in great detail in a book by Melges [1]. Loss of memory goes with loss of time deposits. There is often disorientation in clock time, so that memories cannot complete their necessary temporal integrations. Impaired sequential thinking commonly combines with a severe temporal disorientation in present, past, and future time.

Yet there is no need to visit psychiatric wards to encounter dissolution of the bond between time and memory. It is, in fact, an almost normal ailment of the very old that they have lost part of the capacity to form complexes of time and memory being at the same time disoriented in physical or clock time. In their surroundings the emphasis tends to be on loss of short-time memory. It does not seem to be generally understood how important it is to possess adequate time functions, and yet the evolution has put a special premium on them. Few if any animals can lift out a piece of precise sequential memory from the past, the way man does so easily. Probably man is unique also in possessing anticipation in future time. Apparently the development of mind has depended substantially on the incorporation of time as part of the process.

#### REFERENCE

1. MELGES, F. T. *Time and the Inner Future*. New York: Wiley, 1982.