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Information processing within the central nervous system: From "Pure Mind" to "Pure Brain"

There are at least three different ways to estimate the rate of information processing going on in the human mind-brain. The first approach offers an estimate based entirely upon mental capabilities. The third approach is based soley upon biological properties of the brain. The second approach lies somewhere inbetween, calling upon arguments based on the mind as well as the brain.

All three methods allow a rough estimate of the ratio of conscious to unconscious information processing, and lead to the same conclusion:

The ratio of conscious to unconscious information processing in the mind-brain Å 1 to 10^4 .

Other approaches and estimates are certainly possible. Nevertheless, even if the arguments used here are in error by as much as an order of magnitude (=factor of 10), the conclusion remains astonishing.

Conscious-Memory-Efficiency Approach

This approach relies upon an estimation of the efficiency of conscious thought. It requires two independent approximations:

- The length of one consciously experienced moment
- The maximum number of conscious moments recalled per year

The first approximation is acquired from estimates based upon the conscious experience of

time. The second approximation is derived from rough estimates of memory efficiency.

Conscious Experience of Time

Without delving into philosophical discussions about the nature of observation in the quantum theory, it is reasonable to accept that, for everyday purposes, the spatial world around us is an internal (subjective) construct of our visual, auditory etc. perception of an external (objective) reality. Indeed, it seems only natural, that is, we take it for granted, that there is no distortion of reality along the way from sensory impression to mind-brain comprehension of space: We automatically assume that the geometry we "see in our heads" is the same geometry that "really exists out there". Maybe for this reason, it is difficult for us to accept the possibility that the temporal world around us may also result from a subjective distortion of an objective temporal reality.

Following W. STERN, there is the concept of 'the psychological present^a, namely, the longest time span experienced to be the immediate present or, the maximum time interval between two sensory signals which still allows us to continuously and consciously experience them as a single event without resort to memory. This maximum time span may extend up to ca. 12 sec., . At the other end of human time experience, we have the shortest time span which can occur between two sensory signals in order for us to still be able to differentiate them as separate events. This is roughly 1/18 sec. = 55,555... ms. In other words, we can scarcely hear 18 air pressure oscillations per second as a succession of beats or just barely see 18 pictures per second as a jiggling: More single-frequency beats per second are heard as a single, continuous and deep tone; more pictures per second are seen as a single, continuous motion. Thus, time intervals shorter than about 1/18 sec and longer than ca. 12 sec. elude our conscious expectant attention. In other words, we seem to experience the world around us in conscious 'expectant attention windows^a of maximum 12 sec. length separated by unconsious intervals of at least 1/18 sec.. I will slightly modify the breadth of this 'attention window^a below.

A more careful physiological analysis shows that simultaneity is a relative concept depending upon the particular sensory channel receiving two signals: Roughly speaking, the more information accompanying a signal, the more time that is necessary between signals in order for the mind-brain to be able to consciously process them distinctly. Thus two successive sounds can already be distinguished consciously if they are separated by only 4-5 ms; two touches by 10 ms, whereas two pictures require a duration of at least 20-30 ms between them, . Conversely, sound beats with a frequency higher than roughly 200 250 Hz, skin vibrations with a frequency of more than ca. 100 per second and films with a picture rate of more than about 25 pictures per second will be consciously experienced as a single continuous sensation (tone, pressure or motion) even though they comprise a succession of sensory impressions. Furthermore, and independent of the particular sensory channel involved, a time interval of approximately 30-40 ms between sensations is necessary in order for a person to be conscious of the rank order - which signal came first? - between signals. This brings me back to the estimated 1/18 sec interval between conscious sensations already mentioned above.

Finally, I return to the idea of the necessary duration of a sensation in order to experience it continuously in the present sense of "now": Sensations shorter than 3 sec. in duration are generally overestimated to be somewhat longer, whereas a sensation lasting longer than 3 sec is generally underestimated to be somewhat shorter. Successive sensory impulses following

each other within this 3 sec time window can be comprehended as belonging to the same time-gestalt, whereas this is less possible (to being altogether impossible) for series of sensations occurring within time spans of shorter or longer duration than roughly 3 sec.. From this I slightly modify my above estimate and conclude that we seem to experience the world in 'attention time windows^a of around 3 sec. length separated by intervals of approximately 1/18 sec. Thus, I arrive at the following conclusion:

One consciously experienced moment takes up on the average of $3 \sec + 1/18 \sec$

= 3.0555... sec of lifetime.

It is interesting in this regard to note that shamanistic drumming and rattling aimed at inducing a trance state is typically carried out at a frequency of roughly 3 Hz, i.e. 1/3 sec between beats, namely, at a frequency lying very well within the range of conscious attentive experience.

Memory

Based on the above considerations, over the time of one year a person experiences an average of about $(2/3) \ge 365.25 \le 24 \le 3600/3.0555 \ldots = 6 \le 10^6$ conscious moments (excluding 1/3 of the year for sleep). Accordingly, if a person could remember every single living moment over this same entire time span, he or she would have to be able to store roughly 6 million conscious remembrances every year. But it has already been demonstrated that even a person with an exceptionally gifted memory is only capable of recalling one or more remembrances for roughly 100 days per year, long after this year has passed . Thus, assuming for the sake of argument that a person could recall an average of 6 rememberences for an average of 100 days by date at the end of a year, I find an efficiency of only 0.01%. Interestingly enough, exactly this same ratio will turn up from my data-processing and anatomical considerations of the mind-brain below. This apparent inefficiency of the conscious mind-brain can just as well be understood as an attest to the predominance and efficiency of unconscious information processing in the mind-brain.

Information Theory Approach

Another possible way to grasp consciousness in scientific terms is via information processing in the mind-brain. The data handling activity $A_{\text{consciousness}}$ of the nervous system necessary for the processing of conscious experience can be estimated by the channel capacity or bandwidth necessary to carry the information for a modern multimedia system designed to fill a movie theater audience with the experience of realism:

One single full picture in PAL-resolution of 768x576 pixels (1 pixel = 1 byte = 8 bits) corresponds to 442'368/1024 kilobytes (kb) = 432 kb of information. At a standard rate of 25 pictures per second, this gives a data rate of 10'800 kb/s for a black and white silent film. For color pictures we must multiply this result by 3 resulting in 32'400 kb/s or 32'400/1024 Mb/s = 31.6 Mb/s for a color film without sound. Including audio information from 16 bit stereo sound at a standard CD rate of 44 kHz (88 kb/s = 88/1024 Mb/s = 0.0859 Mb/s), hardly changes this estimate. Rounding up, I find an overall data rate of roughly 32 Mb/s for a full blown

cinema:

$$A_{consciousness} = 32$$
 Mbits/s, i.e., on the order of 10 Mbits/s.

An estimate of the overall activity A_{Total} of the waking brain is not so simple. On the one hand, actual values for the number N of neural synapses in the brain have been obtained either by examining brain sections from sites throughout the brain or by sampling counts made on homogenized brain material. Such estimates give ca. N=2x10¹³ to ca. N=2x10¹⁵ corresponding to an average of 200 to 20'000 synapses, respectively, for each of the ca. 10¹¹ neurons in the brain (cf. e.g.). For the purposes of this analysis, I assume the logarithmic average, namely, $\leq N \geq 2x10^{14}$ neural synapses in the central nervous system.

Now if the neural system optimally encoded information, the amount of information I transferred across each synapse would be 1 bit every time a synapse decided to fire or not to fire, i.e., every time an action potential arrived at the synapse and the activation time t=0.3 ms ran out. There is, however, a lot of redundancy in the handling of data in the brain which most likely serves to reduce the information-loss inherent to thermal disturbance of the quantum firing process. The corresponding value of I is therefore smaller than 1 bit and has been accordingly estimated to be, on the average, on the order of $\leq I \geq =0.03$ bits of information per activation event. (See also .) Finally, I need an estimate of the average activation frequency per synapse $\leq I \geq any$ given time in the brain during the waking state: $\leq I \geq = 0.03$ activations/synapse-s. Then, a (very) rough, "back-of-the-envelope" estimate of the overall information data rate or activity A_{Total} of the waking brain is given by

$$A_{total}$$
 = average number of neural synapses in the brain x
average activation frequency per synapse x
avg. amount of information with each activation (firing decision)

$$\mathbf{A}_{\text{total}} = \langle \mathbf{N} \rangle \mathbf{x} \langle \mathbf{f} \rangle \mathbf{x} \langle \mathbf{I} \rangle$$

 $\begin{array}{ll} A_{total} & = 10^{14} \; synapses \; x \; 0.03 \; activations/synapse-s \; x \; 0.03 \; bits/activation \\ & = 0.0009 \; x \; 10^{14} \; bits/s \\ & = \; 10^5 \; Mbits/s. \end{array}$

The result is

$$A_{total} = 10^4 A_{Consciousness}$$

Once again - recall my discussion of memory above -, *only about 0.01% of all the brain's activity is experienced consciously* (cf., e.g.,). In other words, it is as if roughly 10'000 cinema films are actually going on in the brain all at once, while we are only consciously aware of one of them, indeed, a very particular one transmitted through the sensory channels (sight, smell, sound, taste, touch and balance)!

Altogether then, the data rate processed by the brain is an astronomical 320 Gb/s! Accordingly, one could argue that the birth of human consciousness is a kind of "ignition problem" occuring only if a system is capable of processing, like the human brain, at least 320 Gb/s (or more) of information. Because of the wide range of estimates for the numbers used here, the exact order of magnitude cannot be taken too critically. In any case, however, there's a lot of information

processing going on in the brain, most of which we are not at all conscious of!

Anatomical Approach

This estimation is based upon approximations of the neural distribution within the central nervous system.

Neural distribution within the central nervous system

It is encouraging to note that my estimate of 0.01% conscious brain activity is the same as what we would expect from a simple neuroanatomical comparison of classical conscious and unconscious parts of the central nervous system (=brain + spinal cord). In other words, the interstitial nerve complex lying between the (more or less conscious) sensoric and motoric parts of the central nervous system is generally assumed to comprise the components of a supposedly unconscious "calculating neural network" and is estimated to contain circa 99.98% of all the nerve cells of the central nervous system .) Accordingly, this (very quantitative argument) would also imply that only about 0.01% of all the brain's activity could be experienced consciously.

A certain proportion of this conscious processing may occur interstitially by classical neurophysiological means. Nevertheless, the biochemical calcium hypothesis has long been shown to be severely limited in explaining this . More refined, standard quantum physical considerations explaining the processes providing the interconnection among the nerve synapses in the brain, namely, tunneling at the synaptic clefts, are indeed capable of predicting the above-mentioned consciousness data rate . But what about the other 99.99% of unconscious data processing in the brain? New ideas are still in need.

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