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Sensory Function in Extraterrestrial Beings
(*Fonctions Sensorielles des êtres extraterrestres*)

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ABSTRACT. The laws of physics, as we know them, are assumed to be valid throughout the universe. While we have no definitive knowledge that extraterrestrial life-forms exist, we can, nonetheless, make statements about them conditional upon their existence. All sensory function, at an elementary level, can be shown to be governed by a single, fundamental equation. Moreover, for the simplest sensory system, this fundamental equation can be obtained directly from the uncertainty principle in conjunction with de Broglie's relation. Since quantum physics holds universally, probably the fundamental law of sensation is also universal. Therefore, if extraterrestrials exist, probably their sensory systems operate on principles similar to our own.

RÉSUMÉ. Notre connaissance des lois de la physique nous permet de supposer qu'elles sont valides partout dans l'univers. Bien que nous n'ayons pas de preuve définitive de l'existence de formes de vie extraterrestres, nous pouvons néanmoins faire des hypothèses à leur sujet. Il est possible de démontrer que toute fonction sensorielle, à un niveau élémentaire, est gouvernée par une équation fondamentale unique. De plus, pour le système sensoriel le plus simple, cette équation fondamentale peut être obtenue directement de la combinaison du principe d'incertitude et de la relation de de Broglie. Puisque la physique quantique s'applique universellement, il est fort probable que la loi sensorielle fondamentale est également universelle. Conséquemment, si les extraterrestres existent, il est probable que

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leurs systèmes sensoriels opèrent selon les mêmes principes que les nôtres.

Introduction.

We have not the slightest concrete evidence suggesting the existence of developed life-forms on worlds other than our own. It might, therefore, seem a little premature to elaborate on the function of their sensory systems, whose very existence is questionable. However, just as physics purports to speak meaningfully about the spectra and gravitational fields of stars and galaxies so remote we may never experience them, so too, the theory of biology may, perhaps, strive for comparable universality.

We think an argument can be made to show that if extraterrestrial beings exist their psychophysiological function, at least on a very elementary scale, does not deviate markedly from that of terrestrial organisms. What follows is an outline of that argument expressed as simply as we are able to do. The structure of the argument is drawn from several disciplines: principally biology, psychology and physics. References have been provided for readers who wish to explore the background in more detail.

The laws of physics are usually assumed to be universal. Therefore, on a trivial scale, a lens would be required to produce an image on the "retina" of an extraterrestrial organism in much the same manner as we find in animals on earth.[1] Similarly, if they are to detect compression waves in atmospheric gases, *probably* a membrane similar to our tympanic membrane (ear drum) is needed as a detector although, admittedly, nature is a great innovator and might devise some other form of sound wave reception. However, we are concerned here with sensory function in a more general way than just the structure of individual sense organs. Psychophysical considerations are usually bypassed in speculations about extraterrestrial life, although Baird [1] does set the stage for discussion. We follow in this direction.

There is a plethora of empirical laws (*Sensory experience grows linearly with the logarithm of stimulus intensity*), rules of thumb (*You can generally react more rapidly to an intense stimulus than to a weak one*), and principles (*The sensory experience may fade with increasing exposure*

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[1] Less developed organisms, of course, do not need imaging organs and may make do with other photosensitive tissue.

to the stimulus) which characterize sensory function in higher terrestrial organisms. The question we pose here is whether the same laws, rules and principles can be expected to govern sensory function in extraterrestrial organisms, should it transpire that they do exist. The surprising thing is that one can address this question at all.

To develop the argument, we shall appeal to quantum mechanics, particularly the aspect dealing with the problem of "observation", or more properly perhaps, of perception.

Intellego perception.

From the viewpoint of Erwin Schrödinger, the quantum-object is regarded, during the pre-observational period, as existing in the form of a complex wave which consists of a superposition of a number of constituent waves. Before we actually make the observation, each constituent wave represents one possible state in which the quantum-object might be found. During the observational phase of quantum perception, the complex wave "collapses" into one of its constituent waves, which represents the perceived state of the quantum-object. Quantum perception in Schrödinger's point of view, then, takes the form of a selection of a single choice from among a number of possibilities.

Werner Heisenberg, on the other hand, tended to view quantum perception through the medium of his uncertainty principle. He demonstrated that at the core of microphysics lay a restriction on the precision to which certain quantities such as position and momentum may be known simultaneously. Therefore, prediction of the future (for example, prediction of the future position of a particle), could not be made with certainty. Hence, he was led to his own statement about quantum perception:[2] "Therefore all perception is a selection from an abundance of possibilities [and a limitation of what is possible in the future]." That is, quite remarkably, Heisenberg was driven to much the same picture of quantum perception through his uncertainty principle as Schrödinger was through the medium of his wave function. We call this view of perception *intellego* perception [$intellego = inter + lego$: I choose between], since the process is fundamentally a choice among alternatives.

Although intellego perception is recognized primarily at the microscopic level (i.e. quantum physics), it serves as a useful definition of

[2] Translated from W. Heisenberg, Zeitschrift für Physik **43**, 197, (1927). The parentheses have been added.

perception at the mesoscopic or everyday scale of activity. If I perceive that the sky is red, I select "red" from among the possibilities "blue", "azure", ... in short, from all colors that the sky might have been. If we take this intellego principle as seriously at the mesoscopic as we do at the microscopic level, it provides a theoretical base from which all the empirical laws and rules of elementary perception may be derived. A single equation and single inequality can be shown to be generic of nearly the whole body of elementary sensory laws [2].

Sensory implications.

The gist of the idea is that a mesoscopically steady stimulus (i.e. steady in the sensory laboratory) is really the mean of microscopically fluctuating events. For example, the constant density of an odorant gas is, in effect, the mean of microscopic molecular density fluctuations. The standard deviation of these microscopically fluctuating signals is a measure of the range of "possibilities" considered by the sensory receptor, out of which a single selection may be made. To define the number of possibilities available, we take the ratio of the standard deviation of the stimulus signal to that of a reference or threshold signal. The logarithm of this ratio is then a negentropy [3], information, or a measure of uncertainty in the stimulus with respect to the reference or threshold. We can envisage a steady sensory stimulus as a stationary stochastic sequence of microscopic sensory events. In this brief treatment of the problem we shall regard the steady mesoscopic stimulus as low in intensity with the Poisson distribution governing the sequence of microscopical sensory events.[3] Then it can be demonstrated that for values of the Poisson parameter greater than about 3, the sensory response[4] is given by

$$\frac{1}{2}\ln\left(1+\frac{\Delta\,(stimulus\ intensity)^2}{\Delta\,(reference\ signal\ intensity)^2}\right)\leq 1.8 \qquad \text{(1a)}$$

We shall discuss the biological meaning of this equation later.

[3] Poisson probability is given by $p(x;\lambda)=\frac{e^{-\lambda}\lambda^x}{x!}$, where x is the number of events and λ , the parameter, is equal to both the mean and variance. The entropy is given by $-\sum_{x=o}^{\infty}p(x;\lambda)\log\ p(x;\lambda)$ and can be approximated in closed form for $\lambda>3$ by $\frac{1}{2}\ln(2\pi e\lambda)$.[4]

[4] The extra "1" in Eq (1a) comes by adding the reference signal to the external stimulus signal: The receptor would detect the sum of the two signals.

By sensory response we mean a quantitative measure of the brightness of a light, the loudness of a sound etc. The $\Delta\left(\right)^2$ signify variances which, for the Poisson distribution, is just equal to the mean signal intensity. $\Delta(\textit{reference signal intensity})^2$ will be taken to be constant. For the moment, we regard the 1.8 natural units of information that provide an upper limit to the sensory response as an empirical constant which is approximate.

Eq. (1a) takes us most of the way, but for prolonged periods of observation we must still incorporate the idea of memory. It is not the variance of individual microscopic events but the variance of the mean which is significant at the mesoscopic level. That is, by the correspondence principle, the sensory event experienced by the human observer is not sensitive to individual quantum events but to the mean value of such events. The variance of a stimulus sample of size m (i.e. m terms of a time-series) will be given by $\Delta(\textit{stimulus intensity})^2/m$, so that for prolonged observation we might replace Eq. (1a) by

$$\textit{sensory response} = \tfrac{1}{2}\ln\left(1 + \frac{\Delta\left(\textit{stimulus intensity}\right)^2/m}{\Delta\left(\textit{reference signal intensity}\right)^2}\right) \qquad \text{(1b)}$$

where, to a degree of approximation, m may be taken to be proportional to the time of observation.[5] The $\Delta\left(\right)^2$ may also be read $(\textit{uncertainty})^2$ since, for example, $\Delta\left(\right)^2/m$ is a measure of the perceiver's residual uncertainty in the stimulus value after m time units of observation. That is, mesoscopic perception collapses its "wavefunction" (signal uncertainty) gradually, over a period of time represented approximately by m.

Eqs. (1a), (1b) can now be used, with very little additional mathematics, to produce the various empirical laws of sensation. Details are given elsewhere [5], but the reader may see that in Eq. (1a), when the ratio of variances (i.e. mean intensities) is much greater than one, the well-known law of Fechner emerges immediately: *sensory response* $= a\log(\textit{stimulus intensity}) + b$. This is the law which states that loudness, for example, increases nearly linearly with decibels of mean sound pressure. When the ratio is smaller than one, taking terms of the first order in the Taylor series expansion of $\ln(1+\textit{ratio})$ produces the commonly used power law of sensation. This law improves on Fechner's law by relating, for example, loudness to the mean pressure raised to a fractional

[5] $\Delta\left(\textit{stimulus intensity}\right)/\sqrt{m}$ is the standard error of the mean, but for a more complete discussion please see earlier publications.[5]

power. When m increases in value, sensory response diminishes, referring to Eq. (1b), illustrating the principle of sensory adaptation. That is, sensation such as the perceived intensity of an odor diminishes with time. If m increases to the extent that no further stimulus uncertainty remains, we cease to perceive. Viewed in another way, if we receive all available information about the stimulus, perception ceases. We do not wish to digress here into the biology of the senses, but the full capability of Eqs. (1a) and (1b) can be found in the background literature [5].

Use of the inequality (≤ 1.8) permits us to quantify perceptual events which involve thresholds or limits. For example, we cannot extract from a simple stimulus more information than about 1.8 natural units (n.u.).[6] The problem of discrimination, e.g. the detection of just-noticeable differences (jnd's) in the intensity of a stimulus, is handled by assigning a constant entropy decrement (an information "packet") to each jnd. In this way, as the perceiver proceeds upwards from the threshold of sensation, stacking jnd-increments one upon the other, he or she adds information in units of the information packet. The maximum number of jnd's discriminable, then, is equal to the maximum 1.8 n.u. divided by the information content of a jnd-packet. 1.8 is an approximate value for this maximum.

The appearance of the 1.8 n.u. entropy change is so widespread in sensory equations [5] that one is led to search for its origins in more basic science. So let us now consider the process of sensation at the simplest possible level. We imagine a sensory receptor which will detect a single stimulus quantum in the presence of a single reference quantum. Let us ascribe to the signal quantum a de Broglie wavelength

$$\lambda = h/p, \tag{2}$$

where p is the momentum and h is Planck's constant. And from the uncertainty principle, we write for the energy change, ΔE, associated with the detection of the reference quantum

$$\Delta E(\mathit{reference}) \cdot \Delta t \geq h/2\pi \tag{3}$$

That is, there is uncertainty Δt in the time of detection of the reference quantum, and during this Δt interval the signal quantum is detected.

[6] 1.8 natural units of information $= 1.8/\ln 2 = 2.60$ bits. $2^{2.60} = e^{1.8} \cong 6$ categories (Miller's magical number 7 ± 2).[6]

The two detection events will, therefore, occur nearly simultaneously. Combining Eqs. (2) and (3) we obtain

$$\frac{\lambda\ p\ /\ \Delta t}{\Delta E(\mathit{reference})} = \frac{\Delta E(\mathit{stimulus})}{\Delta E(\mathit{reference})} \leq 2\pi \tag{4}$$

That is, the momentum p of the signal quantum is changed during detection over the time interval Δt, and the force $p/\Delta t$ acts over a distance approximately equal to the de Broglie wavelength of the particle. The result is the energy change, $\Delta E(\mathit{stimulus})$, carried by the incoming stimulus quantum. This energy change will be interpreted as the uncertainty in the stimulus energy. The wavelength λ may be related to the uncertainty in the width of the wave packet which defines the quantum of signal energy [7]. That is, the wave packet comprises wavelengths centered about the de Broglie wavelength. The width of the packet, Δx, cannot be known with precision greater than about λ. We notice that in the process of combining Eqs. (2) and (3), Planck's constant has been removed. Thus, inequality (4) lacks the microphysical metric imposed by h.

Squaring both sides of inequality (4), adding one, taking logs of both sides and dividing by 2 gives

$$\frac{1}{2}\ln\left(1 + \frac{\Delta E(\mathit{stimulus})^2}{\Delta E(\mathit{reference})^2}\right) \leq \frac{1}{2}\ln(1 + 4\pi^2) = 1.85 \tag{5}$$

which is just Eq. (1a).[7] The calculation is order-of-magnitude, so the 1.85 should not be regarded as precise.

While Eq. (1a) is valid for a stimulus consisting of few or many quanta, Eq. (5) was derived only for a single stimulus quantum. Admittedly, also, Eq. (5) depends on an interpretation of de Broglie's wavelength. Therefore, at best we have demonstrated a link between the microscopic and the mesoscopic.

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[7] Eq. (1a) contains *intensity* which may be taken as power, or $\Delta E/\delta t$. Then

$$\frac{[\Delta E(\mathit{stimulus})/\delta t]^2}{[\Delta E(\mathit{reference})/\delta t]^2} = \frac{\Delta E(\mathit{stimulus})^2}{\Delta E(\mathit{reference})^2}$$

as found in Eq. (5).

We can now return to the central theme of the paper: the sensory systems of hypothetical extraterrestrial beings, or for that matter, of any sensating organism. The quantum principle of *intellego* perception, or selection of one from a spectrum of alternatives, when applied to the mesoscopic process of sensation, gives rise to the seminal Eq. (1a), (1b), from which all elementary sensory rules and laws can be derived. But Eq. (1a) is, in principle, derivable from two fundamental equations of quantum physics. Thus the central equation of sensory perception is, in effect, of quantum physical origin.[8]

However, we regard the basic laws of physics as universal, and quantum physics embodies many of these basic laws. Therefore, it is, perhaps, a reasonable conjecture that Eq. (1a), which is derivable from quantum physics, is also universal. That is, the elementary laws of sensation of organisms everywhere may be defined, to a degree of approximation, by Eq. (1a).

We note that Eq. (1a) does not provide the mechanism of sensation, but only the constraints leading to the sensory laws. We cannot, for example, speak at all about the anatomy of photoreceptors in non-earthly beings, nor can we conjecture about the nature of photochemical reactions that may lead to transduction of visual events. We cannot even say that visual signals will be neuron-mediated. But remarkably, we can say that to a degree of probability Fechner's law will be obeyed and will even have been discovered by hypothetical intelligent creatures in far-off societies.

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References

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[2] K.H.Norwich and K.M. Valter McConville, *J. Comp. Physiol. A.* **168**, 151 (1991).

[8] So quantum physics essentially "flanks" Eq. (1a). Quantum physics provided the *intellego* idea from which Eq. (1a) was originally derived. And the essence of Eq. (1a) can be derived *de novo* without reference to the *intellego* idea from de Broglie's and Heisenberg's equations, which are, again, central to quantum mechanics.

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