The Investigation of Consciousness Through Phenomenology and Neuroscience*

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Abstract

The principal problem of consciousness is how brain processes cause subjective awareness. Since this problem involves subjectivity, ordinary scientific methods, applicable only to objective phenomena, cannot be used. Instead, by parallel application of phenomenological and scientific methods, we may establish a correspondence between the subjective and the objective. This correspondence is effected by the construction of a theoretical entity, essentially an elementary unit of consciousness, the intensity of which corresponds to electrochemical activity in a synapse. Dendritic networks correspond to causal dependencies between these subjective units. Therefore, the structure of conscious experience is derived from synaptic connectivity. This parallel phenomenal/neural analysis provides a framework for the investigation of a number of problems, including sensory inversions, the unity of consciousness, and the nature of nonhuman consciousness.

1 Introduction

Veritatis simplex oratio est.
The language of truth is simple.
— Seneca

I take the *principal problem of consciousness* (henceforth, PPC) to be to understand the relation between our subjective awareness and the brain processes that cause it; that is, to reconcile our everyday experience of consciousness with the scientific world-view. Attempts to evade the PPC by redefining consciousness in terms of behavior,

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neurophysiology or other objective phenomena are unsuccessful because it is the PPC that is the critical issue for most people. Thus the PPC will not go away. Naturally, I'm not claiming that there aren't other important problems and interesting questions relating to consciousness, but I believe the PPC is central.

There is little in this paper that has not been said before. My general framework is consistent with John Searle's *Rediscovery of the Mind* (1992), if I have understood it correctly. I have also drawn much from the phenomenologist philosophers, especially Husserl and Heidegger.

If there is anything original in my approach, it is to put in plain language the insights of these philosophers, so that nonphilosophers can understand them. In particular I have avoided most of the specialized terminology of phenomenology, thereby risking a loss of precision for the sake of readability. I have also avoided detailed citation of the literature; a good survey of the philosophical issues can be found in Daniel Dennett's *Consciousness Explained* (1991), among other places, although I do not agree with his conclusions.

2 Unique Properties of Consciousness

> *Mens cuiusque is est quisque.*
> The mind of each man is the man himself.
> — Cicero

Consciousness, in particular the PPC, cannot be investigated in the same way as other scientific questions. This is because science is a public enterprise, which is based on publicly available data, techniques, norms, theoretical commitments, and so forth. Ultimately it is based on shared experiences, as when, for example, we both look at the thermometer and read the same temperature. Science typically sets aside the subjective, private aspects of phenomena (e.g., how warm it feels to me) in favor of the objective, public aspects (e.g., the temperature measurement).[1] Unfortunately, this approach is inadequate for the PPC, since it is precisely the subjective, private aspects that are relevant, for the central characteristic of consciousness is its subjectivity, which is inherently private and "first person."

Second, the most common pattern of reduction adopted in the sciences is inappropriate for consciousness, especially for the PPC. This pattern begins by separating the subjective, private aspects of a phenomenon from the objective, public aspects, for example, subjective warmth from objective temperature. Then the objective aspects

[1] As Searle observes, resolution of the mind-body problem has been impeded by a pun. I will use "subjective" and "objective" to distinguish private, first-person experience from public, third-person observation. This usage should not be confused with the use of "subjective" to mean "biased or distorted" (and therefore "bad"), and of "objective" to mean "unbiased or factual" (and therefore "good"). Of course, the descriptive and evaluative usages are not unrelated, but I will argue that unbiased, factual investigation of private, first person experience is not impossible.

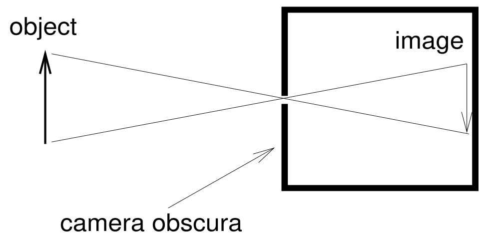

Figure 1: The *camera obscura*.

are reduced to other objective phenomena that are taken to be more fundamental; for example, temperature is reduced to the mean kinetic energy of molecules. The subjective aspects of the phenomenon are simply set aside; they are not reduced; rather, the phenomenon (e.g. temperature) is redefined to comprise no more than the reduced objective aspects. The underlying assumption, which has worked well in the physical sciences, is that the objective aspects are all that is relevant, and that the subjective aspects may be safely ignored.

Such an approach does not succeed in reducing subjective phenomena to objective phenomena, and so it is especially inappropriate when subjectivity is the central topic of concern, as it is in the PPC.

Consciousness is unique among scientific topics in a third regard. The familiar conception of scientific observation and its separation of the subjective from the objective is a distinction between the *observer* and the *observed.* This conception does not apply to consciousness because consciousness is not a thing to be observed; rather it is the act of observation itself, and so comprises the observer and the observed (the content of consciousness). A methodology for the scientific investigation of consciousness, especially the PPC, must take into account these unique characteristics of its subject.

3 A Scientific Approach

An analogy may help us see the way. Consciousness is our opening to the world. It is thus analogous to the aperture of a *camera obscura* (Fig. 1). The aperture is the means by which the inside of the camera "observes" (images) the world outside; it is analogous to consciousness. However, the camera cannot image its aperture, for the aperture is visible only by virtue of its content, the image it transmits (Fig. 2). (We must suppose, to preserve the analogy, that the observer *is* the camera, so there is no way to get outside the camera, and that observation through the aperture is the only kind possible.)

As we may be indirectly aware of other consciousnesses, so the camera may image other cameras, but only from a third-person perspective. One camera cannot look through another camera's aperture; we can see another's aperture (consciousness)

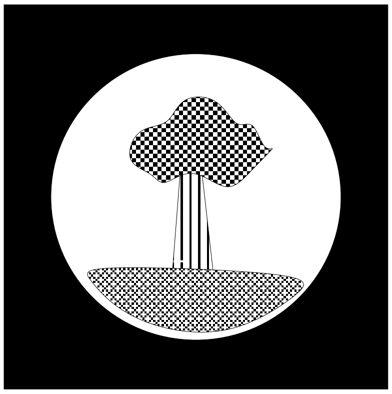

Figure 2: First-person perspective of *camera obscura*.

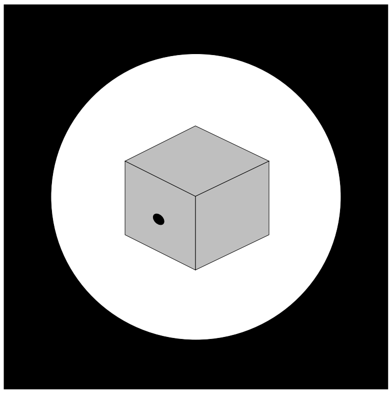

Figure 3: Third-person perspective of *camera obscura*.

only from the outside, and from the outside it looks like a black hole (Fig. 3). By means of a mirror, a camera may even image itself, but its perspective will be third-person.

One camera may form an image of the mechanism by which another camera operates, or by means of a mirror, of its own mechanism (so long as this "vivisection" doesn't prevent it from forming images). By analogy, we can, from a third-person perspective, study the mechanisms of our own consciousness or that of others. The consequent understanding of the mechanism may inform our own first-person experience through our opening to the world.

Although the aperture is visible only by virtue of the images it transmits, some characteristics of the images are more a function of the aperture than of the objects at which it is aimed. For example, we may observe diffraction fringes at the edges of all images. Furthermore, the size of the aperture (analogous to attention) may be adjusted with observable effects on the image (brightness, sharpness, depth of field, diffraction etc.). Thus we can begin to separate the characteristics of the aperture from those of the images it transmits, and begin to relate these phenomena (i.e., diffraction etc.) to the mechanism of the aperture (e.g. a mechanical iris). In this way the first-person (subjective) receipt of images through the aperture is related to the third-person (objective) understanding of the mechanism. By an analogous approach we may hope to relate (first-person) conscious experience to (third-person) theories of the brain.

4 Phenomenological Analysis

> To the things themselves!
> — Husserl

4.1 Phenomena and the Phenomenal World

The inherent privateness of consciousness need not bar its scientific investigation; note that all observation is, in the last analysis, private. Through experience and common training we have developed observational techniques (such as measurement) that lead to agreement among trained observers. Similarly, the scientific investigation of consciousness requires observers that are trained in the "observation" of consciousness (the description of the structure of consciousness independent of its content). The special characteristics of consciousness make this an especially treacherous task (as evidenced by the failure of introspection in psychology), but it can be accomplished. The techniques have been developed especially by the phenomenologists (e.g. Brentano, Husserl and Heidegger). As in other scientific disciplines, unbiased description of the facts will be determined by a consensus of trained observers.

Phenomenology is the study of *phenomena*, the appearances of things to our consciousness, and of the *phenomenal world*, the world as we actually experience it. Etymologically, a *phenomenon* is *something that appears*, and henceforth I will use this word and its derivatives in a technical sense: a phenomenon is something that appears in consciousness, no matter what its cause. The phenomenal world comprises everything we experience, both real and imaginary. For example, it includes pains (both real and phantom), moods, unicorns, internal dialogues, mental images, memories, dreams, expectations, etc. The phenomenal world is the starting point for all science (of the empirical sciences, of course, but also of the so-called *a priori* sciences, since they derive from the apparently invariable structure of the phenomenal world).

Phenomenological training is necessary for the scientific study of consciousness because we have a tendency to describe the phenomena as we think they ought to be rather than as they are. For example, because of some theoretical commitment we might describe the phenomena as "sense data," such as little color patches ("here-now-red," in a well-known example), although we rarely experience raw, uninterpreted sensations of this sort. It takes some practice to set aside our preconceived notions of the phenomena and to perceive them as they are. A few examples will illustrate both the problems and the way around them.

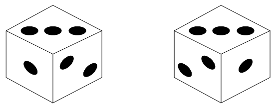

Figure 4: Standard and nonstandard dice.

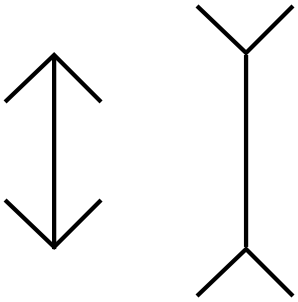

Figure 5: A well-known optical illusion.

4.2 Examples

It is unusual when a phenomenon can be completely described in words, nevertheless a look at the phenomenological accuracy of verbal descriptions can help illuminate the nature of phenomena.

Suppose I rotate an ordinary die in front of someone and ask them to describe what they see. A naive attempt at phenomenological description might be couched in terms of white parallelograms and black ovals that change their shape in a certain regular fashion. This is not an accurate description because, unless you have never seen dice before, you will not experience it as parallelograms mysteriously changing shape, but as a rotating die. Even if you have never seen dice before, you will experience it as a rotating cube marked in a certain way. The skewing parallelograms are a theoretical fiction so far as conscious experience is concerned (though such images do occur on the retina); since they are not what appear, they are not the phenomena.

This example also illustrates that the phenomena depend on experience; unless we are familiar with dice the cube will not be *seen as* a die.

Phenomena typically involve some foreshadowing or expectation for the future. Ordinarily we are unaware of this foreshadowing, but it is "more honored in the breach than the observance." We would be surprised if we saw, as the die rotated, that a side was missing and it was hollow inside, or if we saw a face without spots, or if we discovered it was a two-dimensional picture of a die.

Expectation is also conditioned by past experience: a dice expert's attention would be caught by a nonstandard arrangement of the spots, which would be invisible to the rest of us (Fig. 4).

Consider the following description of Fig. 5: "two lines, a shorter one bisecting two acute angles, a longer one bisecting two obtuse angles." For most of us this is not a phenomenologically accurate description, because we know this is an optical illusion. The fact that it is an illusion is part of our experience of the phenomenon, so a more accurate description is "a well-known illusion in which two lines of the same length appear to have different lengths." This captures both our perception of differing lengths and our awareness that that perception is an illusion. Indeed, for many readers, the most phenomenologically accurate description of Fig. 5 is simply "the Müller-Lyer illusion," since that refers to the phenomenon with all its history and other associations, which are foreshadowed in the experience.

These examples show that the best starting place for describing phenomena is the everyday (i.e. nontechnical) language we use for talking about them. This is because everyday language is a part of our everyday experience of the world, and so it more accurately reflects that experience. Interestingly, it takes some practice to describe phenomena from the everyday perspective (which Husserl called the "natural standpoint"), that is, to accept the phenomena as *data*, the simply *given*.[2]

5 A Theoretical Model

5.1 Topographic Maps

Topographic maps are ubiquitous in the brain. For example, in the *somatotopic* maps of the somatosensory cortex, neurons respond to stimuli in localized areas of the body, and the arrangement of neurons in the cortex corresponds to the arrangement of their receptive fields in the body. In visual cortex we find *retinotopic* maps where spatial distributions of neurons respond to particular patterns of brightness or color in similarly distributed receptive fields in the retina.

In these examples spatial relations among the receptive fields map to spatial relations among the neurons. There are also cases where more abstract relations are mapped to neural location. For example there are *tonotopic* maps in auditory cortex, where pitches are represented spatially. These neurons respond to particular regions of the auditory spectrum, and thus can be said to have a *functional receptive field*, since the field may be nonspatial, e.g., spread over orientation or frequency. More complex combinations also occur; cells in the primary visual cortex are organized in terms of oriented spatial frequency as well as retinal location; each neuron's functional receptive field comprises a retinal receptive field, a spatial frequency band and an orientation band (Fig. 6).

Sensory neurons often form topographic maps, which systematically cover some abstract space with the functional receptive fields of the neurons. Higher brain areas also exhibit topographic maps, although the spaces represented may be more abstract and therefore harder to specify. Topographic maps show us one way the brain constructs the phenomenal world.

[2] Latin *datum*, a thing given, from *dare*, to give.

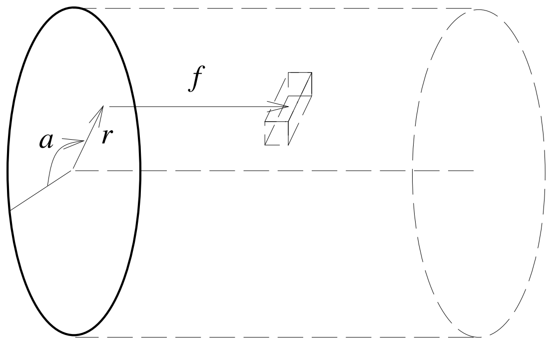

Figure 6: Functional receptive field of cell in primary visual cortex. Axes represent retinal location (r, a) and spatial frequency (f); for clarity, spatial orientation is not shown.

5.2 Phenomenisca

We have been taking the objective view: functional receptive fields and neural activity are both measurable from a third-person perspective. Turning to the subjective view, we can consider a simple account of the conscious effects of these brain processes. A functional receptive field corresponds to a certain aspect of the phenomenal world. For example, if a sensory neuron is tuned to edges of certain orientations in a certain part of the visual field, then its functional receptive field corresponds to the experience of those edges in the phenomenal world; in general, each functional receptive field has a corresponding set of phenomena. Some neurophysiological quantity (e.g., membrane potential, neurotransmitter flux) will measure the extent to which a stimulus is present in the receptive field, and this (objective) quantity corresponds to the intensity of our conscious experience of the corresponding phenomena.[3]

The situation is similar for nonsensory neurons, which also have functional receptive fields, which are defined over the activities of the neurons connected to them. These receptive fields correspond to phenomena that are derivable from the phenomena corresponding to the other neurons.

With this background I will introduce one of the few technical terms that I will use. A *phenomeniscon*[4] is an aspect of the phenomenal world corresponding to a functional receptive field; roughly it represents the phenomena corresponding to the stimuli in that functional receptive field. Some phenomenisca are essentially sense data (e.g., hearing a certain pitch; seeing "red-here-now" or, more realistically, a

[3] It will be objected that this is too simple, since we may be unaware of stimuli to which some of our neurons are responding. That is true, but the objection will be answered by considering interneural connections. Also, I am accepting here the view, hypothesized by Pribram (1971, pp. 104–105), that consciousness is associated with dendritic microprocesses, but not somatic or axonal processes in the neurons, which mediate automatic (unconscious) behavior.

[4] "Phenomeniscon" (accent on penult) is a diminutive of "phenomenon." It reflects the fact that phenomenisca are the "atoms" constituting phenomena, but they are not phenomena themselves.

certain range of oriented grating patches in a certain area of the visual field, i.e. a Gabor wave-packet). Most phenomenisca are constructed from other phenomenisca, so for example the phenomeniscon "rotating-die-here-now" is constructed from phenomenisca corresponding to moving edges and textures, shifting light intensities, etc.

The analysis of phenomena into phenomenisca can be compared to the analysis of a complex periodic wave into a superposition (summation) of simple sine waves; in both cases the analysis has great explanatory and theoretical significance. Like phenomenisca, the constituent sine waves are real in one sense, but not in another, for the sound wave is nothing more than the collective effect of molecules in motion.

That is, the phenomeniscon is a theoretical entity: it cannot be directly observed, but it is postulated for theoretical reasons. In this sense it joins the ranks of other theoretical entities, such as atoms (when atomic theory was proposed), the ether, quarks and potential energy, which are postulated for the sake of the theory and stand or fall on how well they fill that role.

Phenomenisca are like atoms in another way: although they cannot be perceived directly, they can be imagined, which aids our understanding of how they constitute the phenomenal world, and therefore guides our development of experiments and additional theory. For example, the phenomenon of the rotating die is a superposition of many phenomenisca; some are primitive sensory properties, such as patches of color distributions and oriented and moving grating patches projected in three dimensional space. Others are anticipations of future motion and expectations and primings of a wide variety, including those for unseen parts, weight, tactile experiences of texture, descriptive words, dispositions to manipulate and use, etc. Indeed, the rotating die might comprise millions of phenomenisca.

I have noted that some objective quantity, such as membrane potential or neurotransmitter flux, corresponds to the stimulus being in the associated functional receptive field. Corresponding to this quantity on the subjective side I postulate an "intensity" that measures the presence or activity of the corresponding phenomeniscon in the current state of the phenomenal world. That is, the phenomenal world comprises the set of phenomenisca, and the states of the phenomenal world correspond to all the possible phenomeniscal intensities.[5]

In mathematical terms, the state of the phenomenal world is a superposition of all the phenomenisca, each weighted by its intensity. Therefore, states of the phenomenal world correspond one-to-one with vectors of phenomeniscal intensities. In brief, the phenomenisca are the degrees of freedom of the phenomenal world.

A few details need to be taken up at this point. I have said that phenomeniscal intensity corresponds to certain objective quantities, such as membrane potentials

[5]Here and elsewhere, to avoid awkwardness, I will speak as though there is one phenomenal world (as there is, from a first-person perspective). For example, it would be more accurate to say: "That is, *a person's* phenomenal world comprises the set of phenomenisca *corresponding to his or her brain*, and the states of *his or her* phenomenal world correspond to all the possible phenomeniscal intensities *(of his or her phenomenisca)*."

or neurotransmitter fluxes. In fact I think the postsynaptic membrane potential is the best candidate, but identifying the quantity is not critical for my approach. The phenomenisca and their associated intensities are theoretical constructs based on the subjective phenomena, which are our first-person experience corresponding to objective collective processes in the nervous system. Therefore, the phenomenisca have no independent physical existence, and so there is no reason to worry about their exact location or where their intensities reside. An analogy may clarify this: Pressure is a collective effect of individual gas molecules, and for theoretical purposes we may consider the pressure at each point in space; but it would be pointless to look for a "pressure variable" within each individual molecule. Further, just as it makes little sense to talk of the "pressure" of two gas molecules, there may be little point in associating phenomenisca with neurons except in the context of a sufficiently complex nervous system. Thus neurons "acquire" their phenomenisca by virtue of being an element in a complex nervous system, but this is a matter of theoretical convenience, not metaphysics.

Second, I have implied that phenomenisca correspond to "activity sites" (say, synapses) and that their intensities correspond to the physical processes at these sites. In particular, the activity sites and their activities are sufficient to generate all phenomenal states. Equivalently, any difference in phenomenal states reflects a difference in the underlying objective physical processes. Abandoning this assumption would entail accepting nonphysical causes of conscious phenomena, and obviate the need to reconcile consciousness with the scientific worldview (i.e. the PPC).

On the other hand we can ask whether differences in brain state must produce conscious effects (so that brain states correspond one-to-one with states of the phenomenal world). I know of no reason why they must, but it seems the simpler assumption. If some synapses have corresponding phenomenisca and others don't, then we are faced with the problem of explaining this difference.[6] In the absence of contrary evidence it is simpler to assume that all synapses contribute their share to consciousness, though the effects of some may be easier to identify than that of others.

Finally, I must contrast the present model with that of Sir John Eccles (1990, 1993), which is superficially similar. Eccles proposes *psychons* as units of mental activity associated with physical processes in *dendrons*, bundles comprising the apical dendrites of approximately 100 pyramidal cells. The first difference is one of scale: since a dendron contains at least 10^5 synapses, we would have to suppose that a psychon comprises at least 10^5 phenomenisca. However, this is a comparison of apples and oranges, since Eccles' theory is dualistic, for a psychon in a causal primary, which can influence synaptic processes by momentarily altering the quantum-mechanical probability of the exocytosis of neurotransmitter. In contrast, the present model treats phenomenological and physical causation as alternative, but equally valid views of a unitary process. Either may be viewed as primary, as suits the analysis (cf. Pribram, 1993).

[6] The problem of the subconscious is addressed later.

5.3 Construction of the Phenomenal World

Although, in one sense, all feelings, indeed all phenomena, take place in the brain, they are ordinarily projected out into the world. I feel the pin prick in my finger, not in my brain; I see and hear objects "out there," not in my brain; I feel the ache in my stomach, not in my brain. Expectations are also projected: as the die rotates, my expectation for the unseen faces is centered "out there" with the die. Objectively, they may be in the brain, but subjectively they are out in the phenomenal world.

To put the question another way, how are the myriad functional receptive fields assembled to make a world? One way is by simple overlap: typically each receptive field overlaps others in whole or in part. The effect is to connect the receptive fields and therefore to impose a topology on them.[7] Topographic maps also contribute to the construction of the phenomenal world, since receptive fields that are close to each other correspond to nearby neurons. Neural proximity in itself is not very important (though there may be some diffuse electrochemical effects that depend on it), but proximity is correlated with synaptic connection: within a topographic map, nearby neurons are more likely to be connected than distant ones. These connections establish causal relations among synapses, the subjective correspondents of which are considered next.

Presynaptic activity in a sensory neuron depends on the physical processes to which it is sensitive, as well as on postsynaptic activity induced in it by other neurons; presynaptic activity in a nonsensory neuron is entirely a function of postsynaptic activity induced by other neurons. Therefore the intensities of phenomenisca depend on both physical processes and the intensities of other phenomenisca.

More precisely, the dendritic net of a neuron filters the spatiotemporal activity patterns at its synapses, so its own activity reflects these patterns. A dendritic net can be analyzed as a system that performs a spatiotemporal integration of the signals induced in its dendrites by presynaptic voltage fluctuations (MacLennan, 1993). Therefore the behavior of a dendritic net is largely defined by the *characteristic pattern* to which it is optimally tuned (which engineers call its "impulse response").

Correspondingly, the intensity of a phenomeniscon depends on spatiotemporal patterns in physical processes (for "sense data" phenomenisca) and on spatiotemporal patterns in the intensities of other phenomenisca (for "higher order" phenomenisca). These causal dependencies can also be represented by a characteristic pattern, that is, by the spatiotemporal pattern of intensities to which the phenomeniscon is optimally tuned (i.e., which maximizes its intensity). These dependencies can be quite complicated, but some of them are simple.[8]

Figure 7A shows a simple connection pattern among dendrites: the output synapse

[7]From a mathematical standpoint, if one has a set of subsets of a space (such as the receptive fields) and representations of all intersections of those subsets, then one has a representation of a base for a topology on that space, which is sufficient to generate the entire topology.

[8]The dynamics of the phenomenal world is not deterministic, since phenomeniscal intensity may depend on physical processes that are not part of the phenomenal world (as in sensation).

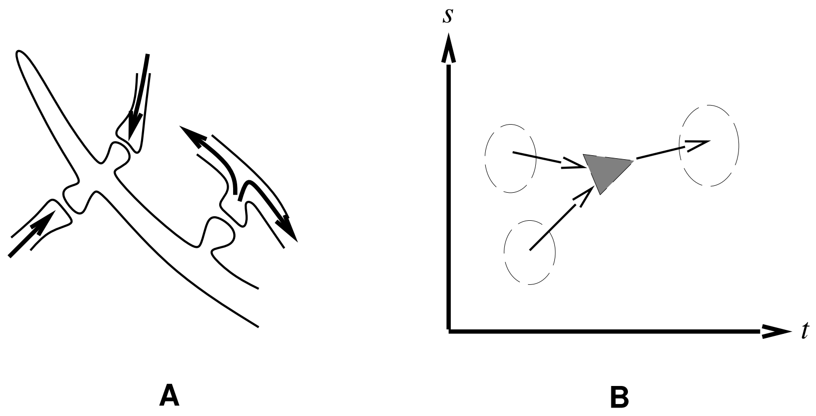

Figure 7: Correspondence between dendritic and phenomeniscal connections. (A) Simple connections between active synapses: activity in the output synapse represents simultaneous activity in the input synapses, and therefore the intersection of the corresponding receptive fields. (B) Corresponding phenomeniscal dependencies (t is time, s is any other property, such as space, pitch or color): high intensity of the later phenomeniscon reflects high intensities of the earlier phenomenisca, as determined by the characteristic pattern connecting them (shown as a triangle).

is active when both the input synapses are active; that is, it is active when both of the corresponding functional receptive fields are occupied. Corresponding to the output synapse is a phenomeniscon, whose intensity is a function of the simultaneous intensities of the phenomenisca corresponding to the input synapses (Fig. 7B).

Other simple connections define other causal dependencies between phenomenisca, such as unions of phenomenisca, sharpening of phenomenisca, appearance and disappearance of phenomenisca, rhythmic and other temporal patterns in phenomeniscal intensity, etc. At a higher level, these connections effect expectations, priming, future inhibition and other dependencies among phenomenisca (Fig. 8).

More generally the characteristic patterns of phenomenisca give the phenomenal world its structure; they assemble the chaos of disconnected phenomenisca into a cosmos. (In ancient Greek, *chaos* originally meant a separating gap, and *kosmos* meant "order," and hence an ordered world.)

The functional role of the characteristic patterns is to organize the phenomenisca into a phenomenal world; the patterns order the phenomenisca in space, time, and other subjective dimensions (pitch, color, speed, orientation, warmth, attractiveness, hostility, etc.). These orders are the basis for constructing phenomena extended in one or more of these dimensions, which leads to the perception of spatiotemporally extended objects and the perception of constancy through change. Change is often continuous: for example, when objects move, they usually change shape or position

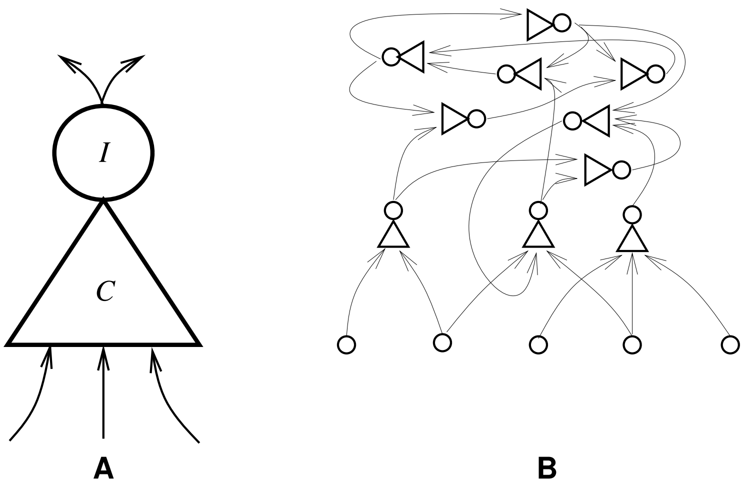

Figure 8: (A) Schematic representation of a phenomeniscon. I is its current intensity, which is a function of its characteristic pattern C and the intensities of other phenomenisca. (B) Simple example of a network of phenomenisca. At the lowest level are "sense data" phenomenisca, which have no associated characteristic pattern (in the phenomenal world); they act like independent variables. Above them are higher-order phenomenisca, with their characteristic patterns which connect them to other phenomenisca and thereby define the structure of the phenomenal world.

continuously, and the pitch and amplitude of sounds often vary continuously.[9]

In neurological terms, stimuli tend to move from one functional receptive field to another that is contiguous or overlapping. In phenomenological terms, intensity tends to flow from a phenomeniscon to others that are "adjacent" (strongly dependent via their characteristic patterns). Conversely, the activation of adjacent phenomenisca is significant because it often implies the underlying identity of something that has changed; contiguous phenomenisca define the likely trajectories (paths of change) in the phenomenal world. Thus the characteristic patterns impart continuity to experience — from moment to moment, from place to place, and from quality to quality. In this way the phenomenal world manifests "being" in "becoming" (constancy through change).

Since learning changes synaptic efficacies, it changes the characteristic patterns of the dendritic nets, which we may call their "resonances." Corresponding to this in the phenomenal world, learning (experience, development, etc.) changes the resonances between phenomenisca. In particular, learning may cause some phenomenisca to become closer together or more distant in the phenomenal world. When a synapse becomes tuned to a particular spatiotemporal pattern in its inputs, the corresponding phenomeniscon appears coincident with a spatiotemporal pattern in the phe-

[9]Even objects that change discontinuously maintain continuity in their unchanging or continuously changing properties.

nomenisca upon which it causally depends (corresponding to the inputs). In effect the phenomeniscon becomes tuned to this pattern, and when a group of phenomenisca become so tuned they may constitute a phenomenon in the strict sense, that is, an appearance of which we are conscious. Thus learning may change the structure and even the ontology of the phenomenal world.

Finally I must explain how this model accounts for nonneural effects on neural processes, for example, the effects of drugs or other substances in the blood. If only certain specific neurons are affected, then they are best treated as *interoceptors*, that is, sensory neurons that monitor internal bodily conditions; for example, such neurons sense the levels of hormones in the blood. If many neurons are affected, then the effects can be treated as alterations of the associated characteristic patterns, which thereby alter the structure of the phenomenal world.

6 Applications

6.1 Necessary Aspects of Subjective Experience

I have suggested that phenomena are irreducible to neural activity, at least by the most popular pattern of scientific reduction. Instead I have described an analysis of the phenomenal world into elementary phenomenisca, which are caused by corresponding elementary processes in the brain, but are not reducible to them. This seems to leave unanswered many of our questions about consciousness, but in fact it provides a framework in which they may be answered.

One set of problems is based on sensory inversions and transpositions. For example, it is asked whether there is any way I could tell whether I consistently experience as low pitches those sound that you perceive as high pitches, and vice versa. I think the apparent possibility of such inversions simply reflects our limited understanding of the structure of the phenomenal world, and that a more detailed understanding would reveal the inevitability of our subjective experience.

Consider first a subjective inversion of loud and soft sounds: could we detect it? This conundrum is partially a consequence of a naive view of aural space as comprising two independent axes representing pitch and amplitude. There seem to be three symmetries and hence three potentially undetectable inversions: loud vs. soft, high vs. low, and amplitude vs. pitch. That is, it is supposed that our subjective experiences of the members of any pair could be reversed (from a first-person perspective) without corresponding changes in neural activity or behavior (from a third-person perspective).

To see that this is not the case, consider amplitude: zero amplitude is not interchangeable with maximum amplitude, since zero amplitude has unique properties. Specifically, at zero amplitude all pitches collapse together; they cannot be distinguished (Fig. 9). (In mathematical terms zero amplitude corresponds to the unique zero of a vector space. The zero vector can be thought of as having any direction

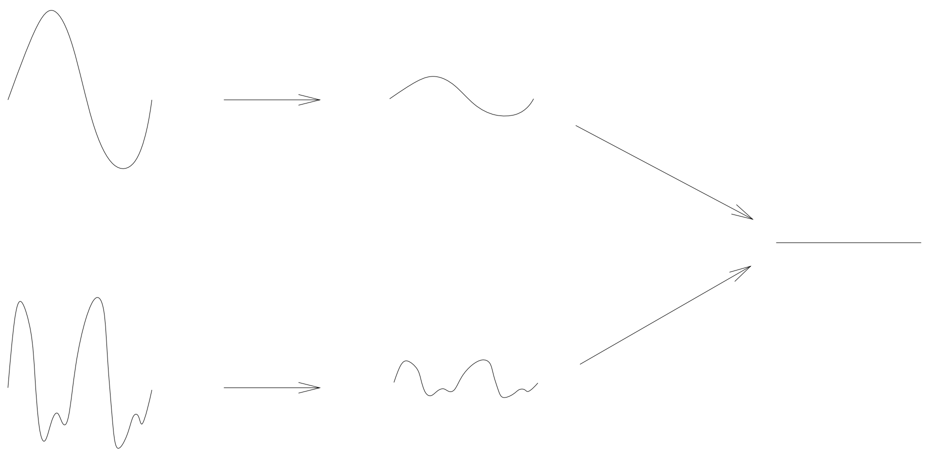

Figure 9: At zero amplitude all pitches are identical.

or no direction. Likewise a zero-amplitude sound can be thought of as having all harmonic contents or no harmonic content.) As a consequence, we find that we could not perceive loud sounds as soft and vice versa, since that would violate the necessary characteristics of sound (i.e., the algebraic invariance, $0\mathbf{x} = 0\mathbf{y}$ for all vectors $\mathbf{x}$ and $\mathbf{y}$); we can distinguish the pitches of loud sounds, but not of silence.

The inevitability of high and low pitch and of pitch vs. amplitude is subtler, but not hard to see. Consider the phenomenology of a sine wave of constant amplitude but slowly decreasing pitch. At high frequencies (above, say, 100 Hz.) its oscillations will be perceived as pitch, but at low frequencies (below, say, 10 Hz.) its oscillations will be perceived as rhythm, that is, as amplitude variations in time. Further, this transition from the perception of pitch to the perception of rhythm is gradual; intermediate frequencies are perceived as both pitch and rhythm.

The phenomenology is exactly mirrored in the neurophysiology. Higher frequencies are tonotopically mapped, that is, frequency is mapped to spatial coordinates. As the frequency becomes sufficiently low that the individual cycles are not integrated by the hair cells and the consequent neural processes, the temporal variation of neural activity (e.g. membrane potential) comes to mimic the oscillations. Indeed, below 5 Hz. neuron firing (and consequent synaptic activity) may synchronize with the sound source, that is, with the individual pressure waves of the sound (Adelman, 1987, p. 91; Suga, 1995, pp. 299–300).

As a result we can see that at low pitches the pitch and amplitude dimensions are not independent; this "contamination" of amplitude (or rhythm) by pitch fixes the low frequency end of the pitch axis. The inherent connection between low pitches and rhythms (amplitude variations) means that we could not in fact reverse our subjective experience of high and low pitches and have everything else (neurophysiology and behavior) remain the same.

The low frequency interaction between the axes also allows us to distinguish the pitch and amplitude axes, since zero amplitude cancels any pitch, but the lowest pitch does not cancel any amplitude (since amplitudes may be distinguished even at the minimum pitch; in neural terms: the neurons with minimum characteristic pitch may display varying activity depending on the signal strength at that pitch.)

Notice that this interaction of the amplitude and frequency axes is in part a consequence of the relative lengths of the time for a cycle of sound and the time for neural processes such as synaptic transmission and charge leakage across the membrane. The point is that low frequency signals must be perceivable as amplitude variations, so physical oscillations significantly higher or lower in their minimum frequency would not display this interaction.

I hypothesize that the subjective experience of "hearing sound" is caused by phenomenisca in a space with a structure like that outlined above. Consequently it is reasonable to conclude that any (nonimaged[10]) oscillation of approximately auditory frequency would be experienced as sound. Therefore, if we ever encounter an organism sensitive to both amplitude and frequency of, say, electrical or magnetic oscillations at these frequencies, then we may conclude that these phenomena would be experienced as sound. In this way we may come, perhaps, to know what it is like to be a bat.

I expect a similar analysis can be applied to vision, specifically to the color spectrum, though it is much more complicated. I anticipate that when the phenomenology of color is fully understood we will find that a spectral inversion, for example, could not occur without violating some of the invariances of visual phenomena.

6.2 Other Applications in Brief

The correspondence between phenomenisca and synapses permits the functional role of consciousness to be integrated into neuropsychological theory. An analogy may be helpful. A spatial arrangement of particles collectively generates a gravitational field, which in turn determines the trajectories of the particles and therefore their spatial arrangement. Thus the microstructure (the particle arrangement) determines the macrostructure (the gravitational field), which determines the microstructure. So also the microstructure of the nervous system, by means of the phenomenisca, generates the macrostructure of the phenomenal world, which in turn guides the dynamics of the nervous system. Since the subjective and the objective are two perspectives on the same processes, we can use whichever perspective has most explanatory value, and switch between them as necessary.

The theoretical model outlined in this paper also provides an approach to problems

[10]It is also significant that, as a consequence of the speed of sound and its frequency, the wavelength of sound is too large to permit the formation of detailed images such as in vision. This of course is another essential characteristic of auditory phenomena. Auditory input is a pair of (time-varying) zero-dimensional (point) fields; visual input is a pair of (time-varying) two-dimensional (planar) fields.

in the unity of consciousness. The characteristic patterns connect phenomenisca to one another and establish the continuity of consciousness across time and space. Conversely, if there are no connections between two groups of neurons, then there will be no causal dependencies between the corresponding groups of phenomenisca. In topological terminology, the space will be disconnected, which means we will have two independent phenomenal worlds.

Therefore, a complete bilateral section of the brain, that is, one that severed all the neural connections between the hemispheres, would effect a disconnection of the patient's phenomenal world. Actual split-brain operations have not been complete; as a consequence the phenomenal world divides into two loosely connected but largely independent worlds. Thus the "unity of consciousness" can be seen as a matter of degree depending on the magnitude of the characteristic patterns of the phenomenisca.

The issue of the subconscious must be addressed briefly, since the apparent existence of nonconscious brain processes would seem to contradict my postulation of a one-to-one relation between phenomenisca and synapses. There are several possible resolutions. First, subconscious processes may correspond to low intensity, loosely connected phenomenisca that do not cohere into phenomena; such coherence would constitute their coming into consciousness. Another, more intriguing possibility is that the so-called subconscious mind is in fact conscious; that is, it has a phenomenal world, which is however only loosely connected to the world of the "speaking mind," which is capable of writing and reading papers such as this one.

The interrelating of phenomenal structure and dendritic structure provides a basis for understanding the consciousness of lower animals. First, the size of the animal's brain is directly related to the number of phenomenisca in its phenomenal world. Therefore some animals with very small nervous systems have such trivial phenomenal spaces that they can scarcely be called worlds; to that extent their consciousness is marginal. Indeed, as noted previously, we may take a certain degree of dendritic complexity to be a prerequisite for the existence of associated phenomenisca. (Asking how many phenomenisca it takes to make a phenomenal world is like asking how many photons it takes to make an image.)

Second, the structure of the animal's brain is directly related to the structure of its phenomenal world. Some animals may have nervous systems of insufficient complexity to impose significant order on their phenomenal spaces (e.g., insufficient to project phenomenal objects into the space around the organism). Their phenomenal worlds and levels of consciousness are correspondingly insignificant. As the ancient Greeks among others recognized, a cosmos presupposes a certain amount of order.

7 Conclusions

The principal problem of consciousness is to understand how brain processes cause our experience of subjective awareness. Since this problem deals essentially with the nature of subjectivity, the ordinary reductive methods of science, which are applicable only to objective phenomena, cannot be used. Nevertheless, by a phenomenological analysis of our experience and by the scientific investigation of the brain, each of which informs the other, we may arrive at a correspondence between conscious phenomena and brain processes. This correspondence is effected by the analysis of phenomena into theoretical entities, the *phenomenisca*, the intensities of which correspond to synaptic activities. As the activity of a synapse is in part a function of spatiotemporal patterns in the activities of other synapses, so also the intensity of a phenomeniscon is in part a function of spatiotemporal patterns in the intensities of other phenomenisca. Therefore, the structure of the phenomenal world can be related to synaptic connectivity. This parallel phenomenal/neural analysis provides a framework for the investigation of a number of problems, including the necessities of our conscious experience, the unity of consciousness and the subjective quality of nonhuman consciousness. Nevertheless, much work remain to be done on both the phenomenological and neurological ends of the correspondence.

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