# PROTOPHENOMENA: THE ELEMENTS OF CONSCIOUSNESS AND THEIR RELATION TO THE BRAIN

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**Abstract:** We argue that fundamental differences of kind prevent subjective experience from being reduced to neural phenomena. Nevertheless, it is possible to perform a quantitative reduction of subjective experience to smaller units of subjectivity in parallel with a reduction of neurological processes to more elementary neurological events. *Protophenomena* are presented as theoretical entities corresponding to the smallest units of subjectivity. Protophenomena are quantitatively simple, having only a degree of presence in consciousness, but cohere into subjectively complex qualia through their connections with other protophenomena. We discuss how the structure of conscious experience emerges from the interrelationship of protophenomena, and apply the protophenomenal approach to some traditional conundrums, such as the inverted color spectrum. We conclude with some speculations about the implications of protophenomenal theory for non-biological consciousness and fundamental physics.

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# THE PRINCIPAL PROBLEM OF CONSCIOUSNESS

## THE PRINCIPAL PROBLEM STATED

The *principal problem of consciousness* is to integrate our feeling of subjective experience with our scientific worldview (MacLennan, 1995); it is essentially the same as Chalmers' (1995) *hard problem*. The root of the problem is that consciousness does not seem to be necessary to the scientific worldview; we can at least imagine a completed physical theory that explains the behavior and cognitive states of humans and other animals in terms of neural processes without any need for conscious experience. Further, physical theory would seem to be compatible with unconscious "zombies" capable of behaving identically to humans (including reports of internal states) by virtue of neural networks implementing the cognitive functions served by consciousness. Yet such a theory would not account for a very important empirical phenomenon: subjective experience.

## SPECIAL EPISTEMOLOGICAL STATUS OF CONSCIOUSNESS

The principal problem arises because of the unique properties of conscious experience. First, consciousness is private, but scientific knowledge is public knowledge; it is founded ultimately on a consensus of appropriately trained investigators. Therefore science has made the most progress on physical phenomena, which are open to investigation by anyone with the necessary training and facilities. Progress is more difficult on consciousness because it is inherently private. Nevertheless, *all* observation is ultimately private (for some *one* makes the observation), and in consciousness studies, as in the better-developed sciences, a body of public fact can emerge through the reports of private experiences by trained observers of differing theoretical commitments.

A second difficulty of consciousness studies arises from the fact that the usual methods of scientific reduction cannot be applied. The first step in such a reduction is separation of the objective and subjective aspects of a phenomenon; for example, subjective (private) warmth is separated from the objective (public) phenomena of temperature and heat. Reduction proceeds by reducing objective phenomena to more fundamental objective phenomena, on which the former supervene. For example, heat is reduced to mean kinetic energy of molecules. Such an approach cannot be used on the principal problem of consciousness, for the phenomenon to be explained is the fact of subjectivity itself. Nevertheless, as will be explained shortly, there is a kind of reduction that can be applied to conscious experience.

Finally, science traditionally attempts to separate the observer from the observed, for its goal is knowledge that is independent of the observer. However, the fundamental relation of consciousness, which Brentano (1925) and Husserl (1931, p. 84) called *intentionality*, is the subject's experiencing of the object. Therefore, the observer cannot be separated from the observed, for it is precisely their relationship that is relevant.

# THE PROTOPHENOMENAL APPROACH

## THE SCIENTIFIC INVESTIGATION OF CONSCIOUSNESS

The special characteristics of consciousness require somewhat different methods from those used in the other sciences. In particular, since all observation is *through* consciousness, we cannot directly *observe* consciousness, but only its content. Nevertheless, it is possible to obtain public facts about consciousness.

An analogy will help to explain the procedure. Any image inside a camera must pass through the aperture of the camera. In this sense, a camera cannot have an image of its aperture independent of any external scene that it is transmitting. Nevertheless, some properties of the image (e.g., focus, depth of field, brightness) depend on the aperture, and with care we may separate the properties of the image that depend on the aperture from those that depend on the external imaged scene. Imaging of simple scenes (e.g., a point source of light, or a *ganzfeld* or homogeneous field) will accent certain characteristics of the aperture, but obscure others, such as those exposed by complex and naturalistic scenes.

So also with consciousness. The structure of consciousness cannot be observed independently of its content, but trained "observers" may distinguish characteristics more dependent on consciousness itself from those more dependent on its content. Such an approach is far from a return to naive introspectionism, for it presupposes adequate training. This may be understood from the camera analogy, for untrained observers would miss certain properties of the aperture, such as depth of field. Similarly to the camera's imaging of simple scenes, observations during meditative practices (e.g., "one-pointing," "emptiness") will expose some characteristics of consciousness but conceal others. These must be supplemented by observations of conscious experience in everyday and laboratory situations.

Through such means a consensus of trained observers will establish eventually a body of facts about consciousness, upon which a scientific theory can be based. What sort of training is required? The best example can be found in *phenomenological psychology* (e.g., Ihde, 1986).

## PHENOMENOLOGY AND NEUROSCIENCE

*Phenomenology* studies the structure of phenomenal worlds. A *phenomenon* (Greek, *phainomenon*) is anything that appears (*phainetai*) in consciousness, including perceptions, hallucinations, thoughts, recollections, anticipations, moods, and desires. However, phenomena occur in relationships of possibility (only certain phenomena are possible, and only certain sequences of phenomena), which together constitute a *phenomenal world*. An adequate scientific theory of consciousness must explain the qualitative character of phenomena as well as the structure of the phenomenal world in which they occur.

We must emphasize that phenomena are much more complex than sense data (such as "red-here-now," that is, a current sensation of red at a given place in the visual field), and so some additional examples may be worthwhile (see MacLennan, 1995, 1996a, for further discussion). To use a classic example (from Husserl's *Cartesian Meditations*, §§17-19), when you rotate a die in front of me, I do not see changing configurations of black ovals in white parallelograms; I see a rotating cube, which I recognize as a die, used in gaming. In such cases, the phenomenologist must be scrupulous in describing what is actually experienced (a rotating die), as opposed to what may be expected to be experienced on the basis of some theoretical commitment (ovals and parallelograms). For example, phenomena are not confined to the here-and-now, but extend continuously into the past and future. The perception of the rotating die includes anticipations of perceptions as it continues to rotate, which are part of the experience. The die phenomenon also incorporates non-visual anticipations and associations, including physical phenomena (its hardness, weight, etc.) and social phenomena (its association with games, gambling, etc.). All this is part of the phenomenological structure of the experienced die and cannot be ignored. These examples may serve to indicate that some training is necessary to gather the data for an adequate theory of consciousness. In short, naive introspectionism is – naive.

Finally, since our ultimate goal is to solve the principal problem of consciousness, we cannot ignore the evidence of neuroscience: a scientific theory of consciousness must be consistent with neuroscientific data, which can also guide phenomenological investigation. We know, for example, that the brain processes quick motions differently from slow ones (Weiskrantz, 1995), because patients with particular lesions can coordinate quick motions but not slow one; therefore we should be alert to this difference in the phenomenal world. This will be our approach: to move back and forth between the domains of neuroscience and phenomenology, weaving the data from both into an integrated neurophenomenology of consciousness.

## PHENOMENOLOGICAL REDUCTION

As previously remarked, science typically proceeds by a reduction of objective phenomena to other, simpler, objective phenomena, but such an approach is inadequate to a scientific theory of consciousness, which must explain subjective phenomena. Nevertheless, a reduction of the complex to the simple is important in any science, and so we may ask how it can be accomplished for consciousness.

We may begin to simplify the phenomenal world by dividing it according to sensory modality; for example, we may treat visual phenomena (perceptions, memories, etc.) independently from auditory phenomena. However, neuroscience informs us that many neurons in visual cortex respond to acoustic stimuli (Pribram, 1991, p. 81, citing Bridgeman, 1982; Pribram & al., 1967; Bavelier & Neville, 2002), and conversely that auditory neurons respond to visual stimuli, thereby aiding face-to-face communication (Calvert & al., 1997). Hence, we should beware of assuming that visual and auditory phenomena, for example, are independent. Nevertheless, they are relatively independent, and may be treated separately as a first approximation, so long as we don't ignore sensory (and, more generally, phenomenal) integration, which is an essential part of conscious experience.

The foregoing may be termed *qualitative* reduction because it separates phenomena that are different in kind; we now turn to *quantitative* reduction, which reduces phenomena to smaller units of the same kind. To understand how this reduction can be accomplished, we can seek some insights from neuroscience.

*Topographic maps*, in which sensory properties systematically correspond to locations in cortex, are ubiquitous in the brain (Anderson, 1995, ch. 10). For example, most readers will be familiar with the *somatotopic map* in the somatosensory cortex, in which regions of the body are represented in corresponding regions of the cortex; the cortical mapping looks like a distorted human body, since larger areas of the cortex are devoted to regions of the body with more sensory neurons. There is a corresponding region of the motor cortex, which is also a topographic image of the body.

Topographic maps are common in all sensory areas. For example, *retinotopic maps* in visual areas have an arrangement corresponding to spatial location on the retina, and therefore to spatial location in the visual field. Topographic maps also give a spatial organization to nonspatial properties. For example, in visual cortex, neurons are spatially organized according to orientation of visual edges, and in auditory cortex frequency is mapped spatially. Bat auditory cortex has topographic maps of Doppler shift to aid in echolocation (Suga, 1985).

Topographic maps suggest an approach to phenomenological reduction. For example, just as the neural representation of certain aspects (e.g., light/dark contrast) of a visual scene can be reduced to the activity of individual neurons in a retinotopic map, and just as the perception of touch across the body is reducible to the activity of individual neurons in a somatotopic map, so also we may reduce a complex phenomenon into more elementary phenomena. Furthermore, it would be reasonable to suppose that these elementary phenomena correspond to the activities of individual neurons in a topographic map.

It is important to stress that these elementary phenomena are quite different from “elementary sense data” (such as “red-here-now”). First, there is much more to consciousness than perceptual experience, and so we must also account for other phenomena such as expectations, memories, imaginations, and so forth. Second, even perception has a much more complex structure than simple spatial maps of physical properties (such as color and intensity). There is considerable evidence (surveyed in MacLennan, 1991) that already in primary visual cortex the visual scene has been transformed by means of a wavelet analysis into a representation in terms of spatially localized oriented patches of restricted spatial frequency. Neurons in higher visual areas will represent even more abstract properties. (As already remarked, rapid motion is processed in different vision areas than slow motion.) Even for those neurons whose receptive field is something so simple as color in a particular place in the visual field, we must explain why activity in that neuron produces the experience of, for example, red-here-now rather than green-here-now. That is, how can we account for the various *qualia* associated with different neurons?

With these caveats in mind we will proceed to discuss the elementary constituents of conscious experience, termed *protophenomena* (or *phenomenisca*; see MacLennan, 1995, 1996a, 1996b).

## Protophenomenon Defined

As a first approximation we may say that a *protophenomenon* is an elementary unit of conscious experience; protophenomena are associated with corresponding *activity sites* in the brain. The identity of these activity sites is unknown, but fortunately the theory of protophenomena does not depend in any essential way on what they are, although of course it is an important empirical question. Likely candidates, such as neural somata, dendritic spines, and ion channels, will be discussed later.

We hypothesize that each protophenomenon has an *intensity*, which corresponds to its degree of presence in the conscious state. This protophenomenal intensity is correlated with activity (e.g., membrane potential, neurotransmitter flux) at the corresponding activity site. For the sake of simplicity, we assume that intensity is a simple scalar quantity and that there is only one kind of intensity; other possibilities will be discussed later.

Since all protophenomenal intensities are (*ex hypothesi*) of the same kind, how are some experienced as red, others as green, and yet others as anger? These subjective qualities come from the structure of the interdependencies of protophenomena.

The plausibility of this claim can be seen by considering topographic maps. What makes one neuron represent a feeling of pain in my toe and another represent a feeling of pain on the tip of my nose, is not any difference in the neurons, but a difference in their location in a somatosensory map. Further, location in the map is relevant primarily because it is correlated with the interconnections of the neurons. Similarly, one neuron represents a pitch of middle C and another a patch of red in my visual field because of the differing networks in which they are connected. By analogy, we expect the qualitative character of protophenomena to derive from their interdependencies with other protophenomena. Nevertheless, a detailed phenomenology of the qualitative structure of experience is one of the greatest challenges facing the protophenomenal theory. As an example of the approach, we will discuss subjective color later.

The investigations of Sur (2004) provide additional evidence for the dependence of qualia on the structure of neural interconnections. In newborn ferrets retinal axons were induced to project into auditory areas (the auditory thalamus and thence to primary auditory cortex, A1) in one hemisphere, while the other developed normally. The effect of visual stimulation to the “rewired” hemisphere was that A1 organized into structures analogous to the orientation maps in primary visual cortex (V1). More significantly, the ferrets responded the same way to stimuli presented to the rewired hemisphere as to stimuli to the normal hemisphere, and exhibited similar visual discrimination in both. Thus the behavioral and neurophysiological evidence together suggest that the ferrets were experiencing visual qualia, even though the stimuli were being processed in what are normally auditory areas.

Although these perceptual examples are the easiest to understand, we must stress that protophenomena are the constituents of *all* phenomena, including perceptions, intentions, anticipations, recollections, moods, internal dialogues, and so on. From another perspective, any neuron that participates in conscious experience has an associated protophenomenon that is the source of the bit of the experience corresponding to activity of that neuron. The variety of protophenomena is as wide as the variety of neural responses.

Up to this point the existence of protophenomena has been motivated primarily by consideration of neural structure. However, this theory also must be consistent with phenomenological observation. Can we observe protophenomena?

Certainly, protophenomena are not salient in ordinary conscious experience; we do not experience them as individuals, and typically we would not note the presence or absence of a particular protophenomenon. (Certain protophenomena may be sufficiently salient to be noticed, but they are atypical.) This might seem contradictory – How can we be unconscious of an elementary constituent of consciousness? – but an analogy may eliminate the paradox.

Macroscopic objects (such as chairs and trees) are composed of atoms, yet we perceive them as wholes, not as assemblages of atoms. Further, although a chair is the sum total of its atoms, the addition or deletion of a single atom will not change the chair as a macroscopic object. We may say that atoms are the elementary constituents of macroscopic objects, but they are not themselves macroscopic objects. So also protophenomena are the elementary constituents of conscious phenomena – they have *essential subjectivity* – yet they are not phenomena themselves (they are *proto*phenomena, which is not the same as "small phenomena"). Therefore the existence of protophenomena is supported by a combination of phenomenological analysis and neuroscience.

Each protophenomenon is a potential constituent of the conscious state, and the intensity of each protophenomenon is its degree of contribution to consciousness. Therefore the *state* of one's consciousness corresponds to the ensemble of protophenomenal intensities. This may seem to leave consciousness disconnected (the "jaggedness" or "grain" problem; Chalmers, 1996, pp. 306–8) and to require an additional integrative element to represent the unity of consciousness. However, no such element is necessary, as the analogy shows. The unity of an object such as a chair arises from the coupling of its constituent atoms; likewise, the unity of consciousness arises from the coupling, or interdependency, of the protophenomenal intensities, which causes the protophenomena to act coherently and constitute a phenomenon.

## Ontological Status

If protophenomena cannot, in general, be observed, their existence might be questioned, so it is worthwhile to say a little more about their ontological status. There are, in fact, several possibilities, but it will take experimental work to discriminate between them.

First, protophenomena might be *theoretical entities*, that is, entities postulated for the sake of the theory, which are validated by the empirical support for the theory and their fruitfulness for further progress (Hempel, 1965, pp. 177–179; Maxwell, 1980). Theoretical entities are common in scientific theories. Atoms and genes were both unobservable when they were first proposed, and they were productive citizens in their theories for many years before they became observable. Quarks are important components of current physical theory, which have not been observed, and are perhaps unobservable in principle. The situation may be analogous with protophenomena: it may be best to treat them as theoretical entities, validated by their role in a theory of the structure of consciousness, until and unless they can be observed empirically (that is, in experience). Eventually, a better understanding of their supporting activity sites might allow phenomenological experiments to be designed in which they are observable.

Another possibility is that protophenomena are emergent properties of sufficiently large and complex brains. Such a situation would not imply that protophenomena are unreal, nor would it imply that there is a certain minimum size or complexity below which consciousness "winks out." To understand this it is helpful to consider another, but better understood, emergent property: sound.

Sound is a compression wave in a medium such as air. Physical theory assigns a pressure to each point in space and accounts for the properties of the sound in terms of the interactions of the pressures of infinitesimal volume elements. (In our analogy, protophenomena correspond to these infinitesimal volume elements, and macroscopic phenomena to the sound wave.) However, we know that air in not infinitely divisible; it is composed of discrete molecules. Pressure is a property of large numbers of air molecules, and it makes little sense to talk of the pressure of a single molecule (or even of a few molecules). Thus, the crucial property for explaining the sound wave, the continuous distribution of pressures, is an emergent property of air. There is no minimum number of molecules that can be said to have a pressure, but from a pragmatic standpoint it is not productive to apply the concept to small numbers. We may find that the situation is similar with protophenomena. It may be worthwhile to speak of protophenomena only in the context of a sufficiently large or complex brain. (Other, more speculative, ontological possibilities for protophenomena are discussed later.)

If protophenomena are associated with activity sites in neurons, then an important question is whether all neurons have activity sites, which amounts to asking whether all neurons contribute to consciousness in some way. Ultimately it is an empirical question, but in the absence of evidence to the contrary, the simpler assumption is that all neurons have activity sites and therefore associated protophenomena. The issue of unconscious mental processes, which might seem to contradict this assumption, as well as the possibility of non-neural activity sites, will be taken up later.

## Protophenomenal Dependencies

Neuroscience suggests that protophenomena are strongly interdependent. For example, neurons typically have thousands of inputs from other neurons; pyramidal neurons in motor cortex may have fifty thousand inputs each. Similarly, neurons distribute their outputs to hundreds or thousands of other neurons. Therefore, whatever the activity sites may be, protophenomena are likely to be comparably interconnected. As a consequence it is reasonable to suppose that most protophenomena are dependent on thousands of other protophenomena.

It seems most likely that it is these interdependencies that give phenomena their subjective qualities. As neurons in visual cortex are not different from those in auditory cortex, but represent the structure of visual or auditory perceptions by virtue of their interconnections (often in topographic maps), so also visual protophenomena differ from auditory protophenomena in their patterns of interdependencies, not in their essences.

The interdependencies among protophenomena determine the patterns of protophenomenal intensities that are possible at a given time and how those patterns may change through time. Thus the interdependencies determine the structure of a person's phenomenal world. They represent the patterns of possible phenomenal change but also the probability of change, which creates phenomenal fields of anticipation and canalizes experience.

We have described protophenomenal dependencies as though they are fixed, but of course this is not the case. Short- and long-term learning affects the number and strength of connections between activity sites, and so they also affect the interdependencies among the protophenomena. In this way the structure of our phenomenal worlds change over time. By creating new conditions of coupling and coherence among protophenomena, learning can create phenomena where they didn't exist; that is, we can learn to become conscious of what was previously unconscious.

What is the nature of the protophenomenal dependencies? This depends somewhat on the precise identity of the activity sites, but neuroscience allows us to make some general observations.

Nonsensory neurons respond to activity in other neurons, and to a first approximation this response may be characterized by a *functional receptive field*, which is a probability density function. That is, we may make a map that represents the degree of response to different combinations of inputs. (If the neuron has one input, it will be a simple curve, such as a bell curve; if it has two inputs, it will be a two-dimensional surface, such as a terrain or contour map. Typically, however, the map is much more complex, for a neuron has thousands of inputs.)

Correspondingly, a protophenomenon's intensity will depend on the intensity of thousands of others. To a first approximation this dependence can be represented by a map showing how the dependent protophenomenon's intensity varies for different combinations of intensities among the input protophenomena. Thus each protophenomenon has a *characteristic pattern*, defined over the intensities of its inputs, which determines its own intensity. Therefore, high intensity will correspond to input combinations near the peaks of the characteristic pattern, and low intensity to the valleys. Further, since the intensity of a protophenomenon corresponds to its degree of presence in consciousness, the subjective quality of a protophenomenon may be identified with its characteristic pattern. This analysis provides at least the beginnings of an approach to understanding the subjective quality of phenomena.

If the activity sites are the axon hillocks, where nerve impulses originate, then the firing of the neuron represents the presence of an input, the probability of which is proportional to the value of the characteristic pattern for that input. That is, the characteristic function is a probability density function representing the probability of the neuron's firing. Simultaneous firing of neurons with the same inputs effectively multiplies their probability density functions, which can sharpen the determination of the input value (Sanger, 1996). On the protophenomenal side, this shows how simultaneous intensity in protophenomena dependent on the same input protophenomena may more precisely define a conscious state.

The foregoing is only a first approximation because many protophenomena respond in a more complex way to their inputs than to simple combinations of intensities. In particular, neurons respond to more than just their instantaneous inputs; they also respond to the recent history of their inputs. (There are many repositories for this history, including membrane potential and charge, which cannot change instantaneously, and accumulations of ions, neurotransmitters, and other molecules.) Therefore, a more precise description of protophenomenal dependency describes how a protophenomenon's intensity varies over time as a function of the time-varying intensities of its input protophenomena. Of course, the precise nature of the dependency depends on the activity sites and the ways in which they interact, which we do not know, but an example may illustrate the approach.

Under the assumption that the activity sites are neural somata (cell bodies) and that protophenomenal intensity corresponds to the membrane potential of the cell body, protophenomenal dependencies are mediated by the axons, synapses, and dendrites. To a first approximation, at least, the dendritic tree can be analyzed as a linear system (MacLennan, 1996b, 1999b). The behavior of such a system is defined by a *characteristic signal*, which differs from the previously described characteristic pattern, in that it is a temporal pattern of changes of input protophenomenal intensities. (In science and engineering, the characteristic signal is called the *impulse response*, since it describes how the system responds to an instantaneous impulse at each input. Its Fourier transform is called the *transfer function*, because it describes the transparency of the system to periodic variations in each of its inputs.) These are just first steps, but they indicate how one might formulate a mathematical theory of protophenomenal dynamics, that is to say, of the foundations of dynamics of consciousness (see MacLennan, 1996b, for the beginnings of a mathematical analysis).

The foregoing discussion applies to nonsensory neurons. To the extent that nonsensory activity sites interact deterministically, so also the interaction of the protophenomena will be deterministic. For sensory neurons, however, the situation is different, because their activity depends on nonneural inputs (e.g., light of particular wavelengths for a cone cell in the retina). Therefore, the intensities of the corresponding protophenomena depend on *extrinsic variables*, which are undetermined in the phenomenal world.

There are other extrinsic effects on the phenomenal world, due to nonneural influences on activity sites. For example, under normal circumstances neural activity is influenced by brain physiology and the physical environment of the body; a more extreme example is a stroke. All of these affect the phenomenal world, but are not determined by the protophenomenal state.

In summary, protophenomenal theory is not causally complete, as we assume physical theory to be. This does not imply, however, that protophenomenal theory is superfluous and physicalism is sufficient, because physicalism cannot account for a fundamental empirical fact: conscious experience.

## CONSEQUENCES

In this section we will discuss briefly a few of the consequences of protophenomenal theory for our understanding of consciousness.

### DEGREES OF CONSCIOUSNESS

The theory of protophenomena accounts for one's phenomenal world in terms of the number of protophenomena and their interdependencies; the protophenomena define the degrees of freedom in the world, and the dependencies (e.g., the characteristic signals) define its structure. Further, the dimension and structure of a phenomenal world are directly related to the number of activity sites and to the organization of their interconnections. Therefore, one can conclude that animals with smaller, simpler nervous systems have a consciousness that is smaller in dimension and simpler in structure than ours. There is no reason to suppose that consciousness "winks out" below the human level or at some other point in the scale of nervous system complexity. Conversely, elephants and whales have brains that are larger than humans', and thus their phenomenal worlds may be supposed to have more degrees of freedom (to accommodate, at least in part, their larger bodies), but that does not imply that the structural complexity of their phenomenal worlds is also greater than ours. Indeed, it is an oversimplification to compare phenomenological structures on the basis of a single dimension, such as "complexity." Therefore, protophenomenal theory provides a basis for describing the consciousness of nonhuman species, but much neurophenomenological research remains to be completed before we will be able to do it in detail.

## NONBIOLOGICAL CONSCIOUSNESS

The theory of protophenomena can help shed light on the perennial question of computer consciousness, for the theory states that protophenomena are associated with certain physical processes occurring in the corresponding activity sites in our brains. We cannot at this time say what those processes are (although some possibilities are discussed below), but we can draw some conclusions nevertheless. An analogy will make this clear. Liquidity is a property of water, but it is a consequence of more fundamental physical properties of $H_2O$ molecules (their finite volume and mutual attraction at close distances). As a consequence, other quite different molecules may be liquid if they have these same properties. Similarly, protophenomena are a consequence of fundamental physical properties of the activity sites in brains. If we could discover or construct nonbiological systems with these physical properties, then we could conclude that they are conscious, but we cannot say whether that will be possible until we understand the requisite properties. They could be quite specific to neurons (e.g., depending on neural physiology), or they might be nonspecific (e.g., any physical instantiation of an *information process*, see below and Chalmers, 1996, ch. 8). Possible embodiments for consciousness will be similarly narrow or wide.

We have seen that solutions for the problems of degrees of consciousness and of nonbiological consciousness both require better understanding of the activity sites, in particular whether isolated activity sites have protophenomena (as opposed to the presence of protophenomena being an emergent property of masses of interconnected activity sites). One way to answer the question would be to identify one or more protophenomena that are sufficiently salient that an observer could report their presence or absence (high or low intensity) in consciousness. If the corresponding activity site could be identified, then, in principle at least, the physical processes at the site could be manipulated to determine their effect on the corresponding protophenomenon. Such experiments are fraught with technical and ethical difficulties, but their possibility shows, at least, that the question has empirical content.

## INVERTED QUALIA

To illustrate the protophenomenal approach, it will be worthwhile to say a few words about the well-known problem of *inverted qualia*. As we will see, the supposed possibility of such inversions typically rests upon inaccurate phenomenology.

We may begin with a pitch inversion: Is it possible that you experience high pitches the same way I experience low pitches, and vice versa? The possibility of such an inversion rests on an inaccurate phenomenology of auditory phenomena, in particular, on thinking of pitch and loudness as two independent dimensions, but they are independent only for relatively high pitches. Frequencies above, say, 100 Hz are perceived as pitch, but lower frequencies (say, below 10 Hz) are perceived as rhythm (periodic loudness variation); intermediate frequencies may be perceived as both. This phenomenological description is confirmed by neuroscience, for higher pitches are represented spatially in the cortex (in tonotopic maps), but at lower frequencies (below about 5 Hz) the nerve impulses synchronize with the sound waves (Adelman, 1987, p. 91; Suga, 1995, pp. 299–300). Hence our experience of pitch is intertwined with our experience of loudness, and the hypothesized pitch inversion is impossible. More precisely, if a person's auditory system were "wired backwards," they would experience sound differently from normal people, and protophenomenal theory could account for that abnormality.

The intriguing idea of a color spectrum inversion can be traced back at least as far as Locke's 1690 *Essay Concerning Human Understanding* (e.g., Hardin, 1988; Nida-Rümelin, 1996; Palmer, 1999; MacLennan, 1999a). To some extent it is an artifact of the idea of a linear color scale, which was a popular research topic in the years preceding Newton's discovery of the spectrum c.1669 (earlier theories of color were less linear; see Gage, 1993). However, since the development of the double-opponent theory of color vision (Hering, 1878) we have known that color has a richer topology than a simple linear scale (for recent versions see De Valois & De Valois, 1988, 1993; Kaiser & Boynton, 1996). (Indeed, the experience of color includes emotional, biological, and cultural connotations, which cannot be ignored in a complete phenomenology, but must be omitted here for the sake of simplicity; see MacLennan, 1998, 1999a, 1999b.)

According to the double-opponent theory, hue is represented on two axes: yellow vs. blue and red vs. green (the color names are approximate and conventional). The axes are determined by four "unique hues," which are experienced as unmixed colors (i.e., pure yellow, blue, red, green). This model suggests three independent kinds of inverted color vision: yellow-blue, red-green, and an exchange of the yellow-blue and red-green axes (cf. Palmer, 1999), but more careful phenomenology shows that they are impossible (i.e., would create reportable differences in color experience).

First, it has been recognized since ancient times (e.g., Aristotle, *De sensu*, 442a) that yellow and blue are the hues most similar to white and black; yellow is the intrinsically brightest hue, an observation known as the *yellow anomaly*. Therefore, experiential yellow and blue are phenomenologically definable by their relation with the third (supposedly independent) axis of the double-opponent theory: light vs. dark. (The poles of the light-dark axis are identifiable because forms and colors are indistinguishable in the dark.)

Since red and green are not extremes in terms of intrinsic brightness, they are harder to define phenomenologically, but Goethe (1840), a careful phenomenologist, observed that while green is intermediate between the extremes yellow and blue (¶697), red has a different relationship to them. He described how a very pure red "like fine carmine on white porcelain" (¶792) could be produced by an "augmentation" (*Steigerung*) of yellow and blue (¶¶699–703). Indeed, unique-red is a nonspectral hue: an experience of it cannot be generated by monochromatic light.

The essential distinctness of the four polar colors is supported by cross-cultural studies of basic color terms, which also capture phenomenological distinctions (Berlin & Kay, 1969; Kay & McDaniel, 1978; Saunders & van Brakel, 1997).

The phenomenology of color experience is paralleled by neuroscientific accounts of the mechanism of color vision (e.g., De Valois & De Valois, 1993), which explain how the double-opponent representation is derived from the three color-receptors. Phenomenologically they correspond to extrinsic variables because they respond to physical light (which is outside the phenomenological world), but correlated activity in the receptors as a consequence of a large overlap of their response curves will result, though Hebbian learning, in a stronger connection between their associated activity sites, and hence in greater interdependency between the corresponding protophenomena (i.e., structure in the external world comes to be mirrored in protophenomenal structure).

In this way a careful neurophenomenological analysis of color allows us to construct a topology of color experience, that is, a map of its structures of similarity and difference. Further, we may predict how people with abnormal color vision would experience color. Similar approaches may be applied to other sense modalities and to nonhuman sensation. (See MacLennan, 1995, 1999b, for more detail.)

## Unity of Consciousness

It will be worthwhile to say a few words about the unity of consciousness from the perspective of protophenomenal theory. In a sense, protophenomenal theory dissolves the problem: just as there is no need to postulate a reified "phenomenon" to integrate the coherently changing intensities of masses of protophenomena, so also there is no need for a separate "subject" to integrate the totality of protophenomena into a unified conscious experience. Rather, the phenomenal world is unified by the dense net of interdependencies among the protophenomena.

One source of empirical evidence for this theoretical prediction comes from split-brain operations (cerebral commissurotomies), which sever the approximately 800 million nerve fibers of the corpus callosum, and effectively separate one phenomenal world into two (each with half the degrees of freedom). These operations also demonstrate that the unity of consciousness is a matter of degree, not an all-or-nothing property. As the nerve fibers are severed, the phenomenal world of the patient separates into two phenomenal worlds, the protophenomena associated with the two hemispheres gradually decoupling from each other. One "subject" gradually becomes two. (See MacLennan, 1996a, for additional detail.)

## The Unconscious Mind

Simplicity suggests that activity sites are associated with all neurons, since there seems to be no principled reason (at this time) for supposing that some neurons have them, but others don't. However, this would seem to imply that all neural activity is conscious, which would leave the unconscious mind inexplicable. Nevertheless, we will show that several kinds of unconscious neural activity are compatible with protophenomenal theory.

First we must recall that protophenomena are not phenomena; while protophenomena have the property of elementary subjectivity, they are not typically salient in experience. Phenomena are coherent systems of protophenomena, that is, protophenomena whose intensities change in a coherent way. Conversely we may have incoherent protophenomenal activity, which is unconscious because it does not cohere into conscious phenomena. Incoherent protophenomena form a kind of background noise; they are like the air around us, which we do not feel unless it moves coherently (wind).

The brainstem and midbrain seem two likely locations of unconscious mental activity, and the right hemisphere may have a role to play in the imagistic and symbolic processes of the unconscious mind (Stevens, 2003, ch. 13). But surely the neurons in these areas are not essentially different than those in the manifestly conscious left hemisphere. How can we account for the apparent difference in consciousness?

The split-brain patients reveal the solution, for in their brains there are two, largely independent consciousnesses (phenomenal worlds). At first, we encounter only the consciousness residing in the left hemisphere, because it is more verbal; if we are not careful, we will infer that it is the only consciousness residing in the patient's brain. However, by careful testing, including the use of non-verbal means of communication, we discover that another consciousness is also resident. But this shows that there could be other consciousnesses, more deeply buried and less able to manifest their presence through speech and other overt behaviors.

Recall our previous conclusion about the unity of consciousness: it is a matter of degree. Our brains probably generate a number of phenomenal worlds, more or less tightly coupled. In a normal, non-split-brain person, the protophenomena of the left and right hemispheres are strongly interdependent, and create a single world (ego consciousness). But other brain systems (e.g., the midbrain and brainstem) are not so densely connected, and so their phenomenal worlds may be more independent of the ego's; from the ego's perspective (but not their own!), they are unconscious.

It is highly suggestive that in split-brain patients the right hemisphere is able to communicate with the left through the brain stem (which is left intact) or through "external transactions," such as twitching the skin of the face. The left-hemispheric consciousness experiences these communications as inexplicable "hunches." Similarly, communications from brain systems that are loosely coupled with the ego's would be experienced by the ego as hunches, urges, intuitions, dreams, and so forth, that is, as activities of the unconscious mind. It is not an unconscious mind, but rather another conscious mind (or more than one), which cohabits the brain with the ego, but is different from it. Supporting this conclusion is Jung's (*CW* 8, ¶253) observation that unconscious complexes can behave like autonomous personalities.

A third explanation for the unconscious mind presupposes that the activity sites are in the synapses or dendritic trees of the neurons. This is based on the observation that unconscious reflexes are primarily all-or-nothing axonal signals, whereas consciousness is associated with graded dendritic processes in the cortex (Miller & al., 1960, pp. 23–4; Pribram, 1971, pp. 104–5; Pribram, 1991, pp. 7–8). This observation is consistent with the view that the collective unconscious mind is associated with phylogenetically determined reflexes and instincts. According to Jung, the archetypes are contentless perceptual-behavioral structures grounded in our shared biological nature, which acquire content when they are activated and emerge into consciousness (*CW* 9, pt. 1, ¶155; see also MacLennan, 2003, 2006). So also, the axonal wiring of our brains is largely determined by our genetics, whereas the dendritic microstructure is a result of learning and adaptation. The subtle, graded interactions in the dendrites correspond to the interacting protophenomena, which give personal conscious content to activated unconscious archetypal structures.

Where, then, is the unconscious mind? We expect that all three of these processes (incoherent protophenomena, loosely coupled phenomenal worlds, axonal structures) are aspects of what we call the unconscious mind.

# OPEN QUESTIONS AND SPECULATION

## ARE THERE DIFFERENT KINDS OF INTENSITY?

One issue that we must consider is that there might be more than one kind of physical activity correlated with consciousness. For example, if activity is associated with neurotransmitter flux, then it is possible that the (50 or more) different neurotransmitters are associated with qualitatively different protophenomenal intensities. This is made more plausible by the fact that different neurotransmitters have different effects on the postsynaptic cell. A similar situation arises if protophenomenal intensity corresponds to membrane potential, since it is reasonable that depolarization (which moves the membrane closer to its firing threshold) would generate a qualitatively different experience from hyperpolarization (which holds it back from firing). These are all empirical issues, but we are very far from being able to conduct experiments to settle them.

## WHAT ARE THE ACTIVITY SITES?

We have already mentioned the possibility that the activity site is the neural soma and the membrane voltage is its activity. The membrane potential integrates the complex spatiotemporal signals received by the thousands of inputs into the dendritic tree of the neuron, which has been implicated in consciousness, as already mentioned. The generation of the action potential would correspond to (unconscious) transmission of this summation to another neuron.

A different, attractive theory is offered by Cook (2002a), who argues that "the momentary opening of the cell membrane at the time of the action potential is the single-cell protophenomenon … underlying 'subjectivity' – literally, the opening up of the cell to the surrounding biochemical solution and a brief, controlled breakdown of the barrier between cellular 'self' and the external world." That is, normally the neuron's intra- and extracellular fluids are separated and differ in ion concentrations, but when an action potential occurs, several hundred thousand ion channels open, and therefore the intracellular concentrations tend to equilibrate with those outside the cell; in effect the cell "senses" its immediate environment. Hence, according to this theory, the neuronal cell membrane in the region of the axon hillock is the activity site and the ion flux through the membrane is its activity. Furthermore, coherent phenomena are a result of neurons firing in synchrony and "the normal ebb-and-flow in the strength of subjective feeling is real, and a direct consequence of the variable number of neurons participating in synchronous firing" (Cook, 2002a). The other way in which neurons are open to their environment is through their synapses, but Cook sees the role of synapses to be in cognition (information processing) rather than in consciousness (experience). There is much more to this theory than can be treated here; see Cook (2000, 2002a, 2002b, chs. 6–7).

A different candidate for the activity site is suggested by research indicating that conscious experience is associated with the brain's electromagnetic (EM) field (John, 2002; McFadden, 2002; Pockett, 2000, 2002). For example, McFadden's theory, makes two principal claims: (1) synchronous firing of neurons generates an *endogenous EM field* that can influence neuron firing; and this coupling via the EM field is crucial for information processing in the brain; and (2) reportable conscious experience is a component of this EM field that can affect the firing of motor neurons.

It will be worthwhile to make a few remarks on the implications of McFadden's theory for the nature of activity sites. If the first claim, that neurons couple through the brain's endogenous EM field, is correct, then the EM field mediates the interaction of activity sites and therefore corresponds to field interactions between protophenomena. Such interactions would be more diffuse, global, and holistic than those corresponding to synapses and other neural connections. If the second claim is correct, it implies that some or all of the activity sites are outside of the neurons and in the endogenous EM field. This possibility does not contradict the protophenomenal theory, but it requires us to think differently about the activity sites.

There is a mathematical theorem (reviewed in MacLennan, 1991) that proves that any field of finite bandwidth (such as the brain's EM field) can be decomposed into a finite number of simple wavelets (called Gabor elementary functions). The mathematics is the same as that used to prove the Heisenberg Uncertainty Principle, but it was applied by Dennis Gabor (1946) to quantify the amount of information that could be encoded in any signal. He called this quantity, which is equal to the number of Gabor elementary functions into which the signal can be decomposed, the *logon* content of the signal. That is, the Gabor elementary functions are *quanta of information*. (These are quanta of *structural* information, which relates to the degrees of freedom of the signal; this concept is different from the *selective* information treated by Shannon's better known theory; see MacKay, 1969, pp. 178–189; Cherry, 1978, pp. 47–49.)

The calculation of logon content of the brain's EM field is relatively straightforward: the area of the cortex is 2200 $cm^2$; if the spatial resolution of the endogenous EM field is at least 1mm (McFadden, 2002), then its information capacity is about 220,000 logons, but if the resolution extends to 0.1mm, then the field will support 22 million logons. (Divide the area by the square of the resolution; although the exact formula depends on how spatial resolution is measured, it is accurate to within an order of magnitude.) In the latter case, at least, it seems that the field could support the richness of conscious experience.

The exact number of quanta is perhaps not so important as the implication that the elementary units of experience (the degrees of freedom of consciousness) correspond to the information quanta (wavelets) constituting the conscious EM field. That is, the activity sites are the wavelets and their activities (and thus protophenomenal intensities) are the wavelet amplitudes (which, incidentally, are complex numbers, the phase and magnitude of which might be experienced differently). Couplings between the wavelets, and therefore protophenomenal dependencies, are established by the electrodynamics of the brain; that is, both directly by the EM field (Maxwell's equations) and indirectly by influencing the firing of the neurons that generate the field.

## PANPROTOPHENOMENALISM

The foregoing considerations raise interesting questions concerning the activity sites underlying protophenomena. What is it about a physical process that causes it to have an associated protophenomenon? Chalmers (1996, ch. 8) suggests that *physically realized information spaces* might provide the link between physics and phenomenology. Such a space can be experienced in two ways, either externally, as a physical process, or internally, as a phenomenal (or protophenomenal) state. That is, what is perceived by an observer as a physical change in a system is experienced by that system itself as (proto)phenomenal change.

For example, the process of neurotransmitters binding to receptors with the consequent opening of ion channels increases the coupling between the intra- and extracellular spaces, thus decreasing the entropy of the joint system; this coupling can be quantified by the *system mutual information* between the cell and its immediate environment (including its synapses). More specifically, the activation of a particular individual receptor provides an amount of information measured by the *conditional mutual information* of the consequent postsynaptic state, and this increment of information may correspond to intensification of the associated protophenomenon.[1] Similar considerations apply to information processing in non-neural cells, including other somatic cells and microorganisms such as bacteria.

Further, from the perspective of protophenomenal theory, we may speculate that every fundamental physical state (e.g., the quantum state of an elementary particle or field) has an associated protophenomenon. A quantum state change corresponds then to a change of protophenomenal intensity. This does not imply that my desktop computer is conscious, nor that the Internet, the earth, or the universe as a whole is conscious. It only implies that their constituent elementary particles have protophenomena, which could be conscious if organized into an appropriate structure of interdependency. Therefore, we do not have panpsychism (in the sense that phenomenal consciousness is everywhere), but *panprotophenomenalism*, the universality of elementary subjectivity.[2] This possibility is supported by theoretical considerations, which we'll discuss briefly.

That information might be fundamental to physics is not a new idea. For example, Brillouin (1956) investigated the connections between matter, energy, and information, and more recently Wheeler (1994) has promoted the primacy of information under the slogan "it from bit." We have mentioned already that Gabor (1946) developed his theory of information by applying the mathematics of the Heisenberg Uncertainty Principle to arbitrary signals; in effect Heisenberg's principle becomes a special application of Gabor's. As the Heisenberg principle limits simultaneous localization in conjugate variables (e.g. time and energy), so Gabor's principle defines minimum joint indeterminacy in conjugate dimensions (e.g. time and frequency) of any signal. As a consequence, any finite signal may contain a maximum number of quanta of information (its logon content). Gabor also showed (following Heisenberg) that indeterminacy is minimized by certain mathematical functions (Gaussian-modulated complex exponentials; see Fig. 1), which are identical to the *coherent states* or *wave packets* that represent particles in quantum mechanics. Thus, the elementary carriers of information are mathematically identical to the elementary particles of physics, and it is perhaps not

[1] Definitions of system mutual information and conditional mutual information can be found, for example, in Hamming (1980, §7.6).

[2] Panprotophenomenalism is an instance of *double-aspect monism* or Chalmer's (2002) *type-F monism*; the approach has its roots in Russell (1927). From quite different considerations, Jung concluded, "psyche and matter are two different aspects of one and the same thing" for "the biological instinctual psyche, gradually passes over into the physiology of the organism and thus merges with its chemical and physical conditions" (Jung, *CW* 8, ¶¶418, 420). See also Jung & Pauli (1955) and Stevens (2003, pp. 79–88).

unreasonable to conjecture that they also correspond to the elementary units of consciousness.

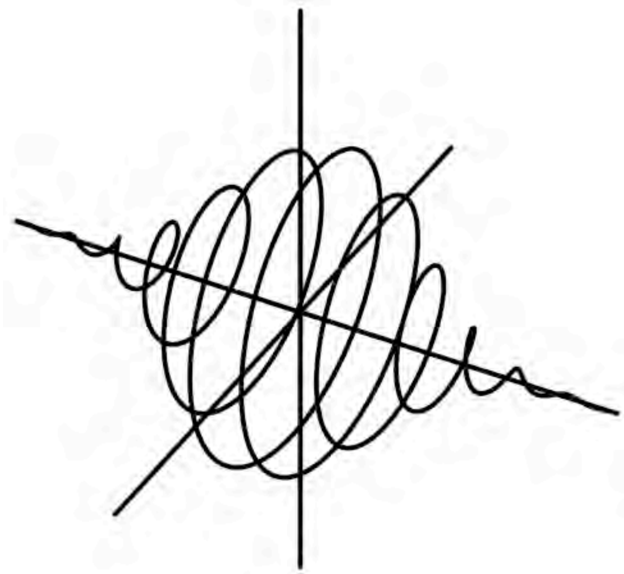

***Figure 1.*** *Gabor Elementary Function (Gaussian-modulated complex exponential). The elementary units of consciousness, information, and the physical world? (The central axis is time, and the other two are the real and imaginary parts of the function. From MacLennan, 1991.)*

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