

WHY NEURAL SYNCHRONY FAILS TO EXPLAIN THE UNITY OF VISUAL CONSCIOUSNESS

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ABSTRACT: A central issue in philosophy and neuroscience is the problem of unified visual consciousness. This problem has arisen because we now know that an object's stimulus features (e.g., its color, texture, shape, etc.) generate activity in separate areas of the visual cortex (Felleman & Van Essen, 1991). For example, recent evidence indicates that there are very few, if any, neural connections between specific visual areas, such as those that correlate with color and motion (Bartels & Zeki, 2006; Zeki, 2003). So how do unified objects arise in visual consciousness? Some neuroscientists propose that neural synchrony is the mechanism that binds an object's features into a unity (e.g., see Crick, 1994; Crick & Koch, 1990; Engel, 2003; Roelfsema, 1998; Singer, 1996; von der Malsburg, 1996, 1999). I argue, on both empirical and philosophical grounds, that neural synchrony fails to explain the unity of visual consciousness.

Key words: attention, binding, consciousness, feature ambiguity, neural synchrony, unity

Introduction

A central issue in philosophy, cognitive psychology, and related neurosciences is the problem of feature-unified objects of visual consciousness. This problem has arisen because we now know that an object's stimulus features (e.g., its color, texture, shape, etc.) produce activity in separate areas of the visual cortex (Felleman & Van Essen, 1991). For example, recent evidence indicates that there are relatively few, if any, neural connections between specific visual areas, such as those that correlate with color and motion (Bartels & Zeki, 2006; Zeki, 2003). The question of how neural activities in separate areas of the visual cortex function to produce feature-unified objects of consciousness is often referred to as

AUTHOR'S NOTE: I thank the Editor, Armando Machado, and two anonymous reviewers for helpful suggestions. I would also like to thank Michael Barber, David Chalmers, John Halpin, Jesse Prinz, George Terzis, Kevin Vallier, and Kenneth Williford for helpful comments on earlier drafts. Parts of this manuscript were presented at Toward a Science of Consciousness, the sixth biennial Tucson conference on consciousness, sponsored by center for consciousness studies at the University of Arizona (April 2004); Neurophilosophy: The State of the Art, held at the California Institute of Technology (June 2005); and The Minnesota Philosophical Society Meeting (October 2005), held at the University of St. Thomas. I thank all of the participants at these conferences for their useful suggestions. Please send all correspondence to Eric LaRock, Department of Philosophy, Oakland University, Rochester, MI 48309, USA. Email: larock.consciousness@gmail.com

the object feature binding problem (see Bayne & Chalmers, 2003; Crick, 1994; Crick & Koch, 1990, 1998, 2003; Engel, 2003; Milner 1974; O'Reilly, Busby, & Soto, 2003; Singer, 1996, 1999; Treisman, 1996, 2003; van der Velde & de Kamps, 2006; von der Malsburg, 1996, 1999). Some prominent neuroscientists argue that neural synchrony is the mechanism that binds an object's features into a unity (e.g., see Crick, 1994; Crick & Koch, 1990; Roelfsema, 1998; Singer, 1996; von der Malsburg, 1996, 1999). On this account, an object's features are said to be bound together as a unity because the underlying neurons of those features fire in a correlated fashion. As von der Malsburg observes: "If, during a time interval, the signals on a set of neurons are found to be significantly correlated, the set is interpreted as being bound during that interval" (1996, p. 137). I argue, on both empirical and philosophical grounds, that neural synchrony fails to explain the unity of visual consciousness.

The paper is organized as follows. There is a brief discussion of the visual system and vision-related binding problems. I subsequently utilize the work of Crick (1994) and Crick and Koch (1990) to elaborate the neural synchrony approach to binding. Finally, I argue that neural synchrony fails to explain the unity of visual consciousness.¹

Multiple Areas of the Visual System

Contemporary neurobiology indicates that visual consciousness relies upon the specialized activity of neuronal assemblies distributed throughout the visual hierarchy (Felleman & Van Essen, 1991; Zeki, 1994). For example, as one gazes upon a maple tree, the maple's retinotopic pattern is rapidly laid out on the surface area of V1. Neurons in areas V1 and V2 respond to primitive visual features, such as edges and contours, in a variety of orientations (Grosf, Shapely, & Hawken, 1993). Once a relatively stable figure of the maple has been established and segregated from its background in these lower areas, attentional mechanisms transmit information about the maple downstream for further processing in specialized areas of the ventral and dorsal pathways, also known as the "what" and "where" systems (Mishkin & Ungerleider, 1982). The ventral system's neuronal pathway projects from the occipital lobe to the inferior temporal lobe (IT); it plays the functional role of processing information about an object's shape, color, and texture. The dorsal system's neuronal pathway projects from the occipital lobe to the parietal lobe (7a); it performs the functional role of processing information about an object's location and size. The middle temporal and middle superior temporal lobes (MT and MST) process movements associated with individual objects or collections of objects against stable or relatively stable background conditions. Thus, visually perceiving the maple's features on a blustery day would at least involve the relevant firing activities of specialized neuronal subassemblies in areas V1-4, IT, 7a, MT and MST. It is worth mentioning that over 30

¹ I also discuss why Crick and Koch's (2003) recent neural coalitions view does *not* suffice as a binding mechanism.

specialized processing areas have been discovered in the visual cortex (Engel, 2003). Although this functional specialization has enabled the brain to process information efficiently, it also implies several vision-related binding problems.

Vision-Related Binding Problems

One such problem is the object feature binding problem. This problem arises because we now understand that an object's stimulus features (e.g., its color, texture, shape, motion, etc.) are correlated with activity in separate areas of the visual cortex (Felleman & Van Essen, 1991). For example, the neural connections between specific visual areas, such as those that correlate with color and motion, are sparse at best (Bartels & Zeki, 2006; Zeki, 2003). Moreover, neuropsychological evidence indicates that damage to neurons in V4 produces achromatopsia, i.e., loss of color perception (Meadows, 1974); damage in IT produces associative agnosia, i.e., the inability to identify shapes (Kosslyn & Koenig, 1995); and damage in MT produces akinetopsia, i.e., loss of motion perception (Zeki, 2003; Zbil, von Cramon, & Mai, 1983). Additionally, studies also show that neurons in the parietal lobes respond to the spatial features of an object, such as its size and location (Kosslyn & Koenig, 1995; Stein, 1992; Treisman, 2003). The parietal lobes are located in an entirely different visual pathway than the neural regions that correlate with the stimulus features of an object's shape, color, and texture. This evidence is compatible with and supportive of the idea *that* representing the individual features of an object depends on specialized neuronal subassemblies in separate areas of the visual cortex (see also Prinz, 2000), but we are not at all certain *how* feature-unified objects are produced in visual consciousness. The question of how neural activities in separate areas of the visual cortex operate to produce feature-unified objects of consciousness is referred to as the object feature binding problem. Bayne and Chalmers (2003) articulate this problem as follows:

The notion of objectual unity is closely tied to a central issue in cognitive psychology and neurophysiology. When I look at a red square, the color and the shape may be represented in different parts of my visual system. But somehow these separate pieces of information are brought together so that I experience a single red square. . . . This phenomenon is often referred to as binding, and the question of how it is achieved is often referred to as the binding problem. (p. 25)

Since appraising Crick and Koch's approach to the object feature binding problem is the central focus of the paper, I will mention only briefly in this context a few other vision-related binding problems.

In addition to the object feature binding problem, there are other kinds of vision-related binding problems, such as binding the parts of an object into an integrated, structured whole. When I gaze upon the letter T, for example, I notice that it is comprised of two lines with distinct orientations (namely, horizontal and vertical), which exhibit definite spatial and structural relations to each other. The horizontal line is on top of the vertical line. It is now understood that the individual

parts of an object elicit neuronal responses in different columns of V1 based on each part's unique spatial orientation (Hardcastle, 1998; Tanaka, 1993). Somehow the spatial and structural relations of an object's parts (such as the vertical and horizontal lines of the letter T) are established so that the cognitive subject experiences a single, structured whole. The question of how the spatial and structural relations of the parts of an object are established is referred to as the problem of part binding (see Treisman, 1996, 2003; see also Hummel & Biederman, 1992).

Objects are located in space relative to other objects. For example, there is a spatial relation that holds between a vertically oriented cup and a table's horizontal surface when the cup is on top of the table (cf. Hummel & Biederman, 1992). Given combinatorial possibilities, the cup could have been to the left of, or below the table, etc. Bayne and Chalmers have characterized the visual experience of the spatial relatedness of objects as follows: "We can say that two conscious states are spatially unified when they represent objects as being part of the same space" (2003, p. 25). But, as we discovered earlier, object features and object locations elicit responses from neurons in entirely different visual pathways, namely the ventral and dorsal pathways, respectively (Mishkin & Ungerleider, 1982; see also Treisman, 1996; 2003). This raises the question of how we connect objects to their current locations, which is known as the problem of "location binding" (Treisman, 1996, p. 171).

There are, of course, many other forms of binding. For example, there is also the problem of explaining how information from sensory and non-sensory modalities becomes integrated. How does one explain the sensory-motor binding processes involved in coordinating the perceived location of a rapidly approaching baseball with the trajectory of one's swinging bat? Visual experience rarely, if ever, occurs in isolation from other perceptual phenomena. A person's unified phenomenal experience of a live musical concert, for example, would likely correlate with a plethora of functional roles performed by distributed neuronal constellations within several brain modalities that subserve vision, audition, tactile stimulation, emotion, and mood. It is now known that emotional experience is associated with several distinct neuronal regions (e.g., the rostral anterior cingulate cortex, an emotion processing subsystem connected to other emotion subsystems such as the amygdala, orbitofrontal cortex, sectors of the anterior cingulate cortex, and paralimbic structures) and typically involves somatic, perceptual, and/or recall-based cognitive activities (see Kafetsios & LaRock, 2005; Lane, 2000). Thus, cognition and experience typically involve many modalities at any given time. This suggests that any forthcoming solutions to unimodal binding problems would still leave unanswered the explanatory question of multimodal binding. The aforementioned problems are important binding problems in their own right, but space will not permit a thorough analysis of all of them here. For the purposes of this paper, I focus on the object feature binding problem. Let us now consider Crick and Koch's neurobiological explanation of the unity of an object's features in visual consciousness.

Crick and Koch's Neurobiological Approach to Unified Visual Consciousness

Though Crick and Koch (1990, 1994, 2003) address three vision-related binding problems in their research, they are principally concerned with providing an account of the binding processes that explain the unity of an object's features at the level of visual consciousness. This calls for an elaboration of Crick and Koch's approach to each problem in turn. By doing this we can delimit and clarify the specific kind of binding problem that Crick and Koch regard as central to their research program on feature-unified objects of visual consciousness. The first type of binding problem that Crick and Koch discuss concerns how retinotopically arranged neurons in V1 can bind together the component parts of oriented lines or corners. Crick and Koch maintain that this primitive form of binding is explained in terms of individual neurons responding rapidly to the points that comprise an oriented line or corner of an object (1990, p. 269). The inputs to (and behavioral responses of) these neurons have a genetic basis. This early neuronal response capacity is rapid and automatic and therefore probably "evolved out of the experiences of our distant ancestors" (Crick, 1994, p. 209). In fact, the decay rate of the representation of such visual primitives is roughly half a second or less (Gray, 1999). This rapid type of memory is referred to as iconic memory (Crick & Koch, 1990). Gray points out that the perceptual subject's ability to visually scan a given scene between saccadic eye movements can be "as brief as 100 ms" (1999, p. 34). Recent evidence, for example, has shown that neurons in different columns of V1 that respond to the same orientation will respond in a coordinated fashion to an object that exemplifies that orientation. This is consistent with the idea that the coordinated activities of lower-level neurons could play a role in constructing oriented lines of objects (see Hardcastle, 1998; Terzis, 2001). It is likely that the receptive field properties of these neurons have become specialized (or "tuned") over long periods of evolutionary development in order to carry out these basic operations. This might explain why the size of receptive fields of neurons in V1 is comparatively small. Because this lower-level form of binding is limited to the construction of oriented lines, and occurs at the preattentive level of visual information processing, V1 is probably not the locale (or neural correlate) of visual consciousness (see Gray, 1999). Empirical evidence suggests further that visual hallucination can happen for a period of time after V1 has been severely damaged. And persons with blindsight—a visual disorder caused by damage to cells in V1—can still be conscious of certain visual features, such as motion (Prinz, 2000). This is because the processing site for motion receives a direct visual input that bypasses V1 (Zeki, 2003). Consequently, the evidence gathered thus far indicates that V1 may be necessary as a source of inputs to higher regions of the visual cortex, but could not be the neural correlate of feature-unified objects of visual consciousness (see Crick & Koch, 1995; Prinz, 2000).

The second kind of binding problem that Crick and Koch (1990, 1994) address has to do with our ability to recognize familiar visual shapes in unfamiliar contexts. It is proposed that visual recognition occurs when a stimulus has been

matched (“bound”) with previously learned/stored information. Crick and Koch (1990, 1994) maintain that this form of information storage is correlated with the connective strengths of neurons at higher levels of the visual system, such as IT. In fact, neuropsychological evidence has shown that persons with associative agnosia disorder have undergone damage to cells in IT and, as a result, have severe difficulty recognizing the shapes of objects they consciously perceive (Efron, 1968; Farah, 1990). It is possible, therefore, to have visual consciousness of objects even if one loses the ability to recognize such objects. It would be a mistake, then, to conflate visual consciousness and visual recognition.² Moreover, the size of the receptive fields of neurons in IT is comparatively large, and, as a consequence, these cells are indifferent to the size, spatial position, and orientation of objects in one’s visual field (Luck & Beach, 1998). The implication is that recognition tasks, correlated with activity in IT, abstract away from the vantage point of the perceiver. Nevertheless, the mechanism that underlies visual consciousness of objects must account for the vantage point of the perceiver (presumably because visual consciousness of objects is always tied to a certain vantage point). Neural activity in IT cannot account for the vantage point of the perceiver. It follows that neural activity in IT cannot be the sole mechanism that underlies visual consciousness of objects.

We now come to Crick and Koch’s central concern: a solution to the object feature binding problem. This problem arises because we now know that an object’s stimulus features generate activity in specialized neural areas distributed across the intermediate level of the visual cortex. Crick and Koch formulate the problem as follows:

The different cortical areas respond, in general, to different features. For example, neurons in area MT are mostly interested in motion and depth, those in area V4 in color and shape, and those in 7a in position in space relative to the head or the body. So far no single area has been found whose neurons correspond to everything we see. How is it, then, that we seem to have a single coherent visual picture of the scene before us? (1990, p. 267)

Indeed, because the stimulus features of objects do produce activity in distinct subpopulations of neurons distributed across the intermediate level of the visual cortex, it is difficult to see how unified objects arise in visual consciousness. Crick and Koch (1990, 1994, 2003) provide neuropsychological and neuroanatomical evidence to illustrate why the object feature binding problem should count as a distinct binding problem in its own right. First of all, well-known

² This does *not* mean that stored information of the shapes of objects, correlated with higher levels of the visual cortex, cannot influence visual consciousness. In the concluding section of the paper I will argue that higher-level interpretations can act as top-down influences on the lower-level neural assemblies responsible for generating differing orientations of objects. If correct, this would imply that there is a connection between learning and visual consciousness, in the sense that interpretations are formed on the basis of previously experienced objects of the visual world.

neuropsychological evidence indicates that damage to neurons in V4 produces achromatopsia (loss of color perception). Damage in MT produces akinetopsia (loss of motion perception; see Crick & Koch, 2003). These results are compatible with and supportive of the claim that V4 and MT are not only the processing sites of color and motion, respectively, but they are also the representational sites of such features (see Crick & Koch, 2003; Prinz, 2000; Zeki, 2003). Recent neuroanatomical evidence further corroborates a separation between processing sites. Derived from the monkey visual cortex, this neuroanatomical evidence indicates that the subpopulations of cells that underlie color and motion project in a juxta-convergent fashion to areas in entirely different visual pathways, namely the parietal and temporal areas (see Crick & Koch, 2003; Zeki, 2003). It is therefore doubtful that the experiential unity of colored objects in motion (e.g., the visual experience of a cardinal in flight) could be explained *merely* in terms of neural interactions between the specialized areas of the visual cortex, since the connections between some of these areas are probably sparse at best (Bartels & Zeki, 2006; Zeki, 2003).

Even so, some might claim that the object feature binding problem is a pseudo-problem because it is ultimately based on some false assumptions about the relationship between the mind and the brain, such as the assumptions of modularization and of localization. The main reason for this claim is that even if everything we knew about the brain were true, it would not require any binding between separate areas of the visual cortex. For example, if we think more holistically about the activity of the brain as a single unit, the whole binding problem evaporates on grounds that *a particular part* of the brain could function as a convergence zone and, hence, there would be no need for physical interconnections among all of the visual areas involved in object perception.³

In response to this objection, Crick and Koch could say that it is highly improbable that there could be such a convergence zone due to the combinatorial capacity problem: the virtually unlimited combinations of features that are represented throughout our lives would seem to far exceed the neural machinery with which we are equipped (Crick, 1994; Crick & Koch, 1990, 2003; cf. Roelfsema, 1998; von der Malsburg, 1996, 1999; Singer, 1996, 1999). Presumably, this is why the brain evolved specialized subsystems. Crick and Koch articulate this point as follows: “One reason for these multiple areas is that to handle all activity in one single very large neural net, with everything connected to everything else, would make the brain both cumbersome and prohibitively large”

³ I thank two anonymous reviewers for *Behavior and Philosophy* for posing this objection. It might also be helpful to note that one of the principal reasons why some neuroscientists propose neural synchrony as a solution to the object feature binding problem is because they recognize that there are very few, if any, neural connections between some specialized areas of the visual cortex. As we shall see, the proponents of the neural synchrony hypothesis emphasize that the temporal correlation of neuronal firings (rather than physical interconnectivity) is the distinctive neural activity that underlies object feature binding in visual consciousness. Whether neural synchrony suffices to explain the conscious visual unity of an object’s features will be addressed later in this paper.

(1990, p. 267; see also van der Velde, 2006; von der Malsburg, 1996). The combinatorial capacity problem is deeply related to the issue of how we are able to experience novelty in object perception. For example, think about a child who is visually aware of a zoo animal, such as a peacock, for the first time. The *novel combination* of the peacock's contours and brilliant colors has not been previously experienced by the child and yet the animal appears to the child as a unitary entity, not as a set of unconnected visual features. An analogue from language could be employed to exemplify this point: as language allows for a virtually unlimited variety of sentences, so also visual perception allows for an unlimited number of combinatorial possibilities (Crick, 1994). In other words, because of the novelty endemic to object perception, appealing to previously learned visual information (correlated with a particular part of the brain, or even in several parts of the brain) could not suffice to explain visual consciousness of all the objects we encounter throughout our lives. Similarly, it is not clear that the connective strengths of neurons can handle familiar objects from novel perspectives. Novelty has many guises. The location of an object can change both egocentrically (i.e., relative to the head or body) or allocentrically (i.e., relative to the locations of other objects in the environment). Due to combinatorial capacity limitations, then, it is unlikely that the convergence of information about an object's features to a particular part of the brain could *fully* explain how we consciously perceive the novelty endemic to objects.

Having looked at how Crick and Koch could reply to this objection, I would like to provide one further reason to rebut the claim that the object feature binding problem is a pseudo-problem. Why provide an additional reason? Because some might reply that underlying the object feature binding problem is the assumption that to perceive feature-unified objects is to *build* a picture of the world.⁴ Thus, it would be helpful if one could provide some additional evidence supporting the idea that visual consciousness of feature-unified objects involves cognitive processes of binding. I think the very fact that we can produce illusory conjunctions (i.e., combine features from the wrong objects) argues in favor of the view that we do perform the function of binding. Treisman and Schmidt's (1982; see also Treisman, 2003) experimental work on illusory conjunctions has provided dramatic confirmation for the existence of cognitive processes of binding. In one experimental setup, subjects were shown two colored letters at the same time: a green T and a red O. The experimenters found that when the focus of attention was prevented by means of a brief presentation of the letters, subjects would experience illusory conjunctions; the subjects reported seeing "a red T when a green T and a red O" were presented at the same time (Treisman, 2003, p. 99; see also Treisman & Schmidt, 1982; Treisman & Paterson, 1984). Consequently, red, rather than green, was bound to T and the result was an experience of illusory conjunctions. What is interesting is that these subjects have still performed the function of binding, albeit of an illusory conjunction sort. Now, the object-feature binding would be a pseudo-problem only if we did not perform the function of binding. But

⁴ I thank a reviewer for *Behavior and Philosophy* for suggesting this criticism as well.

we do perform the function of binding (even if, at times, such binding comes in the form of illusory conjunctions). Therefore, the object feature binding problem is not a pseudo-problem.

How do Crick and Koch propose to explain object feature binding? Crick and Koch (1990) allege that our conscious awareness of the unity of an object's features is explained in terms of synchronized (or semi-synchronized) neuronal activity in the relevant parts of the visual cortex. The primary theoretical requirement of this model is correlated firing among a group of neurons at a frequency in the 40-70 Hz range. This form of correlated firing supposedly suffices to explain the perception of feature-unified objects. As Crick and Koch observe, "in neural terms binding means the temporally correlated firing of the neurons involved. In other words, neurons in different parts of the cortex responding to the currently perceived object fire action potentials at about the same time" (1990, p. 270). A synchronized ensemble of neurons could be conceived as analogous to a group of violinists who play in perfect timing throughout a musical score. This useful image underscores the idea that neural synchronies express phase-locking characteristics. Neuronal synchronies are phase-locked in the sense that if the rate of firing of some neurons within a given population slightly speed up or slow down, the remaining neurons within that population will also speed up or slow down to maintain the same speed with the others. Hence, the dynamical character of neural synchrony (see also von der Malsburg, 1996, 1999). The philosophical upshot of Crick and Koch's view is that the representational unity of an object's features corresponds to a subset of temporally correlated neuronal events in the visual cortex: "At any moment consciousness corresponds to a particular type of activity in a transient set of neurons that are a subset of a much larger set of potential candidates" (Crick & Koch, 1990, p. 266). What they mean by "corresponds to" is that unified visual consciousness is wholly explainable in terms of, and therefore reducible to, neural synchrony. Incidentally, their commitment to reductionism as a method of explanation is not limited to the area of visual consciousness. For example, Crick claims that "each of us *is* the behavior of a vast, interacting set of neurons" (1994, p. 203; my italics). Metaphysically speaking, their view is compatible with type-type identity theory, which says that the mental is reducible to the neural (see Place, 1956; Smart, 1959; cf. Armstrong, 2000). To substantiate the claim that neural synchrony is the mechanism that explains the unitary character of an object's features at the level of consciousness, Crick and Koch appeal to experiments conducted on cat primary visual cortex. These research findings indicate that neurons exhibit synchrony in response to a moving bar. The experimental results also reveal that correlated firing among a group of neurons is much stronger in response to a single moving bar as opposed to a pair of moving bars (1990, p. 271). I might add that there are some implicit advantages to the neural synchrony view. First, it is compatible with the functional specialization of our visual anatomy and thus does not posit a convergence zone to account for unified object representations. Second, the neural synchrony hypothesis does not require physical interconnections between all visual areas in order to explain the unity of an object's features in visual consciousness. As it turns out, neural

synchrony has been observed between neurons whose locale is in entirely different hemispheres of the brain (Engel et. al., 1990; see also Engel, 2003). Thus, the neural synchrony view is consistent with an account of large-scale binding, not simply local binding (see Varela & Thompson, 2003).

Crick and Koch (1990, 1994, 2003) recognize, however, that the neuronal synchrony view has important challenges that it must overcome if it is to successfully account for feature-unified objects at the level of visual consciousness. One such challenge that it must address is the feature ambiguity problem. The feature ambiguity problem can be articulated as follows: Imagine that one is viewing two objects at the same time, for instance, a red circle and a blue square in a child's toy box. Presumably the stimulus features of these two objects will activate separate neuronal assemblies simultaneously; however, this implies a problem for the theory of neuronal synchrony. It is unclear how synchronized neuronal activity could know how to assign the appropriate shape with the appropriate color when competing objects are viewed simultaneously. Along with Crick, one might ask, "How could the brain know which color to put with which shape?" In other words, if awareness corresponded merely to rapid (or sustained) firing, the brain might easily confuse the attributes of different objects (1994, p. 210).

Crick and Koch (1990, 1994) invoke the functional role of attention to solve this problem. It is proposed that attention operates in a serial or sequential fashion, marking the features of individual objects at distinct times by causing individual neuronal assemblies to fire in synchrony. These time-indexed neuronal assembly firings are supposedly the correlates of a particular visual object and its respective features. On this view, "what matters is not just the average rate of firing of a neuron but the exact moments at which each neuron fires" (1994, p. 211). On this temporally successive model of the attentional mechanism's visual operations, the distinct subpopulations of neurons that correlate with the representational features of the red circle (namely, its shape and color) fire vigorously at one time (say, t_1) for approximately 100 milliseconds, and the distinct subpopulations of neurons that correlate with the representational features of the blue square fire vigorously at another time (say, t_2) for approximately 100 milliseconds. Hence, the neurons that underlie the representational features of the red circle and the blue square never fire at the same temporal interval. By attending to the representational features of each object at separate times, Crick and Koch infer that conscious awareness depends on and is the result of this serial process: "This form of transient binding probably depends on a serial attentional mechanism, sometimes called the spotlight of attention" (1990, p. 269).

As it happens, in a recent paper Crick and Koch (2003) provide further elaboration of their position concerning the role attention plays in binding an object's features together when competing objects are simultaneously present before one's visual field:

Several objects/events can be handled simultaneously—more than one object/event can be attended to at the same time—if *there is no significant*

overlap in the cortical neural network. . . . If there is such an overlap, then (top-down) attention is needed to select one of them by biasing the competition among them. This [attention based] approach largely solves the classical binding problem, which was mainly concerned with how two different objects/events could be “bound” simultaneously. On this view, the “binding” of the features of a single object/event is simply the membership in a particular coalition. (p. 123; author’s own italics)

Even on this recently proposed cellular coalition (i.e., assembly) model, visual attention is still required to select (or “mark”) a group of features as belonging to its respective object when two or more objects create significant overlap in the cortical hierarchy during the perceptual event. It is proposed that visual attention selects a coalition of cells when competition among neural groups occurs, and that it is in virtue of this attentionally selected coalition that the perceived unity of an object’s features is produced: “In general, at any moment the winning coalition is somewhat sustained, and embodies what we are conscious of” (Crick & Koch, 2003, p. 121). In other words, Crick and Koch implicitly assume that if their neural account of consciousness passes the test of object feature ambiguity, then it should be able to explain object feature binding.

Limitations of Neural Synchrony: Empirical and Philosophical Considerations

Recent empirical evidence strongly suggests that neural synchrony is not enough to explain unified objects at the level of visual consciousness. First, neural synchrony probably cannot account for the enduring character of object representations in visual consciousness because of its fleeting nature. In other words, the visual experience of an object *persists* beyond the subpopulation of cells that fire in synchrony in response to the object (see O’Reilly et. al., 2003). As O’Reilly and colleagues observe, once an object is removed from a subject’s visual field and the neuronal assembly that subserves that object’s features ceases firing, there is no indication of that assembly’s neurons being bound and “yet we can have enduring representations of bound features, so somehow this problem needs to be addressed” (2003, p. 171). What O’Reilly and colleagues have in mind is the experience of the continuous (or diachronic) character of unified percepts. Phenomenologically speaking, the conscious mind does not perceive the world’s objects/events in discrete temporal intervals. Rather, the experiential unity of a scene’s component objects/events bears the distinct phenomenal feature of continuity, the unbroken stream of consciousness that James (1890) and Dainton (2000) have so deftly characterized in their phenomenological analyses. The perceived unity of objects in visual space seems to be experienced along with a feeling of the continuity of time. There is, in a sense, a coalescence of space and time in the experience of object perception. There are different forms of temporal unity associated with object unity in visual consciousness. These forms are expressible through an asymmetry claim: unity over time implies unity at a time, but unity at a time does not necessarily imply unity over time. For example, the

visual subject can be aware of the distinct features of an object at separate times in the visual processing stream (see Bartels & Zeki, 2006; Moutoussis & Zeki, 1997; Zeki, 2003; Zeki & Bartels, 1998)⁵; but the visual subject can also be aware of the coalescence of those features as unified wholes over time. Now, since the experience of the representational unity of an object's features persists beyond the subpopulation of cells that fire in synchrony, the experience of such diachronic unity is irreducible to neural synchrony.

Second, temporal synchrony could play a functional role other than binding an object's attributes together. For example, it could be that neural synchrony fundamentally explains the flexibility of our cognitive architecture rather than its binding capacity. Neuronal flexibility underpins an account of how specialized neurons (e.g., those representing color, texture, motion, etc.) can be recruited to participate in distinct assemblies of neurons at successive times. Because of combinatorial capacity limitations, the brain has likely developed an efficient strategy to represent the individual features of objects when two or more objects share some of the same features in a given visual scene. For example, the very same neurons that represent the color red for one object (O1) could represent the color red for another object (O2). This is possible because the neurons that represent red for O1 could fire in synchrony at some distinct time (say, t1) and then the very same neurons could fire in synchrony at a later time (say, t2) in order to represent red for O2. The brain likely developed this flexible strategy (in the form of successive chains of synchronized neural assemblies) in order to overcome combinatorial limitations. But providing an account of cognitive flexibility is not equivalent to providing an account of binding. Therefore, the very mechanism that underlies cognitive flexibility—namely, successive coalitions of neurons firing in synchrony—is not the same mechanism that explains binding.

Third, the experimental research has indicated that neural synchrony results primarily from “moving stimuli and is notoriously difficult to measure with stationary stimuli” (Hummel & Biedermann, 1992, p. 509; see also Gray, 1999). In fact, the experimentation of Tovee and Rolls (1992) indicates that neurons in IT of alert monkeys show *no* signs of synchrony when those neurons are activated by stimuli that are stationary. This has dramatic consequences for the neural synchrony hypothesis. Because IT cortex probably plays a central role in object recognition, and thus probably plays an integral role in feature integration as well, Tovee and Rolls (1992) concluded that the absence of synchronized neuronal activity in IT strongly suggests that we should reject a synchronization-based mechanism of feature binding (see also Gray, 1999; Shastri & Ajjanagadde, 1993). It is difficult, then, to see how neural synchrony could be an adequate binding

⁵ For example, recent data strongly suggest that the perception of color occurs before the perception of motion by approximately 80 ms; locations, however, are perceived before the perception of colors (Bartels & Zeki, 2006; Zeki, 2003). These data, in other words, reveal that there is an *asynchrony* of the neuronal activities correlated with the stimulus features of an object. Thus, not only are the neuronal events that correlate with an object's features distributed in space (i.e., separate areas of the visual cortex), but they are “distributed in time as well” (Zeki, 2003, p. 215).

mechanism, since some of the objects we perceive in both natural and artificial environments (e.g., mountains, boulders, houses, etc.) are *stationary*. Although objects may be stationary, we and our receptors rarely are.

Fourth, the experimental data used to confirm the temporal correlation hypothesis were obtained from both anaesthetized and awake animals, namely, cats and monkeys (see Engel et. al., 1990; Gray & Singer, 1989; Shadlen & Moshvov, 1999). In fact, Crick mentions that much of the experimental work is performed on “anaesthetized animals who are not conscious” (1994, p. 15). That is to say, synchronized neuronal firings in the 40 Hz range occur in response to visually presented objects in the brains of both conscious and unconscious animals. We, therefore, cannot claim that neural synchrony is the distinctive neural correlate of unified visual consciousness. Moreover, neuronal synchrony correlates strongly with preattentive awareness, i.e., unconscious activity in V1 (see Gray, 1999; Luck & Beach, 1998). It seems to me that a critical question naturally follows from this data: *How can synchronized neuronal firings in the 40 to 70 Hz range be the direct neural correlates of feature-unified objects of consciousness if such “specialized” neuronal activity correlates with preattentive awareness (i.e., unconscious activity) as well?* What this experimental data intimates is that visual consciousness of object-feature unity (OFU) and synchronized neuronal firings (SNFs) cannot be identical, since SNFs also correlate directly with unconsciousness (UC). In other words, identity is a symmetrical relation. So, if visual consciousness of OFU is fully explainable in terms of SNFs, then visual consciousness of OFU and SNFs will share all and only the same properties. Since visual consciousness of OFU cannot share the property of UC, visual consciousness of OFU and SNFs cannot be identical. Or, if we think of the above relata as holding a transitive relation, then we end up with absurdity: if visual consciousness of OFU and SNFs are neurobiologically equivalent and SNFs and UC are neurobiologically equivalent, then visual consciousness of OFU and UC are neurobiologically equivalent. Evidently, the temporal correlation hypothesis explains too much; the same neuronal mechanism (SNFs) allegedly explains both stimulus-related binding correlated with consciousness and stimulus-related binding correlated with unconsciousness.

Fifth, we discovered that Crick and Koch invoke the notion of an attentional mechanism in order to solve the feature ambiguity problem. This seems like a plausible inference to draw. Nonetheless, Crick and Koch implicitly assume that if their neural theory possesses the explanatory tools requisite to explain object feature disambiguity (OFD), then it should also provide a viable account of object feature unity (OFU). They appeal to attentional mechanisms in order to explain OFD, and then infer that membership in a neural coalition, which is selected by attentional mechanisms, is enough to explain OFU. As they put it:

If there is such an overlap [in the cortical neural network], then (top-down) attention is needed to select one of them [i.e., a coalition of cells] by biasing the competition among them. . . .On this view, the “binding” of the features of a single object/event is *simply* the membership in a particular coalition. (2003, p. 123; my italics)

This inference, however, is not warranted. Even if an explanation of feature disambiguation could show how an object's representational features are selected ("marked" or "labeled") when competition occurs, this would not automatically guarantee an account of how such features, once selected, are bound together to form a unified object of consciousness. Which is to say: feature disambiguation does not entail feature binding. To further clarify and motivate this point, an illustration may be helpful. Imagine a grid of lights, such that each light is labeled to represent an individual feature of an object. To simplify matters, the total number of objects that can be represented by the grid is five. The labels that represent an object's features at any given moment are distributed throughout the grid-like system; the label for "red" is above the label for "circle" and the label for "motion" is above and to the right of the label for "red," and so forth. Since an object's features are represented (via labels) in a distributed fashion, we need a mechanism to disambiguate an object's respective group of features when competing object features light up at the same time. One way to know which features belong to their respective objects is by means of a selecting (or "marking") mechanism. In the case of the grid, an electrical switch causes ("selects") the correct coalition of labeled lights to turn on (or "fire" more brilliantly than competing sets of lights) at a distinct time. Notice, however, that *simply because we have a mechanism that selectively activates the correct set of features distributed throughout the grid-like system, we have yet to explain how those features, once selectively activated, are bound together to form a single unitary object as opposed to an unconnected group of features.* Thus, selecting the correct set of features (when competition occurs in the cortical neural network) entails disambiguation, but disambiguation per se does not entail binding. For why not suppose that if the selectively activated subpopulations of neurons that underlie the representational states of red and of circle were identical to (or merely strongly correlated with) such subpopulations, that consciousness would actually look like a theatre of separate features minus object unity? What would a theatre of unconnected object attributes look like from the perspective of someone's visual experience? A way of illustrating only briefly this fragmented form of visual consciousness is through a consideration of what it is like to experience the visual world as an apperceptive agnostic. Apperceptive agnosics are persons who have undergone damage to the inferior parietal cortex and, as a result, have difficulty experiencing objects as holistic, unitary entities: in fact, these patients often "describe the world as chaotic or fragmented" (Kosslyn & Koenig, 1995, p. 112; cf. Farah, 1990).

To provide further weight to this criticism, evidence from neuropsychology strongly suggests that attentional mechanisms are not necessary for binding, though they seem to play a central role in feature disambiguation. For example, a variety of experiments have been performed on normal subjects indicating that selecting the correct set of representational features when competition occurs in the cortical hierarchy depends upon the focus of attention (Treisman, 1996, 2003). In one experimental setup, subjects were shown two colored letters at the same time: a green T and a red O. The experimenters found that when the focus of attention

was prevented by means of a brief presentation of the letters, the subjects would experience illusory conjunctions: the subjects reported seeing “a red T when a green T and a red O” were presented at the same time (Treisman, 2003, p. 99; see also Treisman & Schmidt, 1982). Consequently, red, rather than green, was bound to T and the result was an experience of illusory conjunctions. What is interesting is that these normal subjects have still performed the function of binding, albeit of an illusory conjunction sort. Therefore, focal attention is *not* necessary for binding. If binding can take place independent of the disambiguating role of attention, then an account disambiguation (via attention) does not guarantee an account of binding. Hence, OFD does not necessarily entail OFU. Nevertheless, the functional role played by attention implies a *normative* dimension to the disambiguating process: the perceptual subject’s ability to select the *correct* set of features when competition occurs in the cortical hierarchy is directly tied to the subject’s attentional capacities.

Finally, even if binding were to occur because of some yet to be discovered neural mechanism, one could argue that an explanatory gap would still remain between binding and experience. In this respect, Chalmers argues that Crick and Koch do not explain why binding itself should go together with experience: if we are not sure why binding brings about experience, then “telling us a story about oscillations cannot help us. . . .Crick and Koch’s theory gains its purchase by assuming a connection between binding and experience, and so can do nothing to explain that link” (2000, p. 387). Crick and Koch could reply that they are merely attempting to explain *how* the features of an object appear to consciousness in a unitary way. Thus addressing deep metaphysical issues (such as *why* experience should arise from neural activity in the first place) falls outside the scope of their more modest aims.

Conclusion

Because the relation between cognitive neuroscientific concepts and the concepts of experience is asymmetric, it seems that any balanced theory of consciousness (which is not swayed by the winds of neural reductionism or eliminativism) will have to accommodate both personal (i.e., the phenomenological/first-person experience of unity) and subpersonal (i.e., neurobiological/third-person) aspects (cf. Hurley, 1998). In other words, if consciousness is not merely a theoretical posit (to be explained by a matured neuroscience in the future), but counts as a genuine explanandum, then we will have to adopt a wider methodological approach that takes seriously both cognitive scientific data *and* phenomenal experiential data as “reciprocal constraints” towards understanding the nature of consciousness (see Chalmers, 1996, 2000, p. 267; LaRock, 2001; Varela & Thompson, 2003). What role could phenomenological/first-person data play in a theory of consciousness? We might consider, for example, how the person’s interpretations of ambiguous figures supply implicit evidence for this wider methodological approach. A well-known ambiguous figure is the Necker cube. While viewing a Necker cube, many persons

consistently experience the perception of the cube flipping back and forth between alternative orientations. To elaborate how this occurs, I will utilize the experimental research of Kelso and colleagues (1995; see also Varela & Thompson, 2003). Kelso and colleagues (1995) devised an experiment in which persons were asked to view a Necker cube in eight different spatial orientations. These orientations were presented randomly to the persons involved in the experiment. They were instructed to push a button each time they detected a change in the cube's spatial orientation. For the most part, there was no consistent pattern exhibited by the participants' response to observed switching times for each spatial orientation. However, as the orientation of the cube approached that of a square (oriented at 80 degrees), the orientation was perceived for a longer period of time without switching. In light of these results, one could infer that different interpretations of the Necker cube initiated by the person will influence slightly the neuronal bias that underlies the cube reversal (see Varela & Thompson, 2003, pp. 277-278). This suggests that ambiguous figures are experienced differently depending on how they are interpreted by the person. Hence, higher-level interpretations carried out by the person act as top-down influences on the lower-level neural assemblies responsible for generating differing orientations. The person, in turn, experiences the result of these higher-level influences on lower-level processes.

The preceding inference motivates an important question: why do interpretations of ambiguous figures differ? For one thing, figure-ground segregation can involve the deployment of top-down influences from structural information correlated with IT in the case of previously experienced objects (Peterson, 2001). This higher-level influence upon figure-ground segregation is sometimes referred to as the anticipatory role of the imagination. For example, Neisser describes anticipatory images as "plans for obtaining information from potential environments" (1976, p. 131). In this regard, some contemporary theorists hold that what is stored in (or correlated with) IT are 3-D structures whose top-down interaction with incoming information from striate cortex assists in establishing shape assignment (Parker et. al., 1995; cf. Marr, 1982). Physiological evidence indicates that stored structural information from IT can be activated 60 ms after stimulus onset, which ever so slightly precedes the time in which the receptive fields of cells in V2 respond to shaped figures, but not to grounds (Zisler, Lamme, & Schiller, 1996). Thus, the initial retinotopically organized V1 embodies information that operates as salient cues (e.g., cues from shading and depth), causing feedback from 3-D structures stored in IT (Braun, 1993; Ramachandran, 1988; Sun & Perona, 1997). Full image segmentation most likely requires higher-level analysis by the cognitive subject, which would rely upon access to information about the nature and structure of previously experienced objects and scenes (cf. Shadlen & Movshon, 1999). These empirical results show, in other words, that there is a connection between learning and visual consciousness, in the sense that visual interpretations are formed on the basis of previously learned object structures of the visual world.

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Based upon the above data, one might surmise that object memories in the form of 3-D structures fully explain OFU binding in that they detect the internal spatial structure of visual objects. Although this might work in the case of previously experienced objects, we can also represent objects that we have never seen before. So, the appeal to object memories *per se* cannot be a sufficient explanation of OFU. It looks as though, in many cases, we have to be able to represent OFU without access to previously encoded object memories. The invocation of anticipatory images primarily underscores how our cognitive architecture has evolved to process information more rapidly in the case of detectable objects.

In this paper, we examined a central issue in philosophy and neuroscience: the problem of feature-unified objects of visual consciousness. We found that this problem arises, in part, because the stimulus features of an object (e.g., color, texture, shape, etc.) produce activity in separate areas of the visual cortex. We examined neuropsychological evidence in support of this claim. We also discovered that it is unlikely there could be a convergence zone that underlies what we visually experience because of the combinatorial capacity problem: the possible combinations of features that are represented throughout our lives would seem to far exceed the neural machinery with which we are equipped. These (and other empirical) data motivated the central question of this paper: how do feature-unified objects arise in visual consciousness if the features themselves elicit neuronal responses in separate areas of the visual cortex? In response to this question, we considered why some neuroscientists would propose neural synchrony as the mechanism of object feature binding. On the neural synchrony account, it is supposed that if the firings of a set of neurons are found to be strongly correlated with each other, the set is interpreted as binding an object's features into a unity. I argued, on both empirical and philosophical grounds, that neural synchrony fails to explain the unity of an object's features at the level of visual consciousness.

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