Consciousness Research

Conscious Realism and the Mind-Body Problem

by Donald D. Hoffman, Ph.D.

Editor's Note: This is part 1 of a 2-part paper written by Donald D. Hoffman, Ph.D., Department of Cognitive Science, University of California at Irvine, USA

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Abstract

Despite substantial efforts by many researchers, we still have no scientific theory of how brain activity can create, or be, conscious experience. This is troubling since we have a large body of correlations between brain activity and consciousness, correlations normally assumed to entail that brain activity creates conscious experience. Here I explore a solution to the mind-body problem that starts with the converse assumption: these correlations arise because consciousness creates brain activity, and indeed creates all objects and properties of the physical world. To this end, I develop two theses. The *multimodal user interface* theory of perception states that perceptual experiences do not match or approximate properties of the objective world, but instead provide a simplified, species-specific, user interface to that world. *Conscious realism* states that the objective world consists of conscious agents and their experiences; these can be mathematically modeled and empirically explored in the normal scientific manner.

1. Introduction

What is the relationship between consciousness and biology? This question, a version of the classic mind-body problem, has in some form troubled philosophers at least since the time of Plato, and now troubles scientists. Indeed, a list of the top 125 open questions in *Science* puts the mind-body problem at number two, just behind the question (Miller 2005): What is the universe made of? The mind-body problem, as *Science* formulates it, is the question: What is the biological basis of consciousness?

One reason for this formulation is the large body of empirical correlations between consciousness and brain activity. For instance, damage to cortical area V1 is correlated with the loss of conscious visual perception (Celesia *et al.* 1991). If V1 is intact but certain extrastriate cortical regions are damaged, there is again a loss of conscious visual perception (Horton and Hoyt 1991). Damage to the lingual and fusiform gyri are correlated with achromatopsia, a loss of color sensation (Collins 1925, Critchley 1965), and magnetic stimulation of these areas is correlated with chromatophenes, conscious experiences of unusual colors (Sacks 1995, p.28; Zeki 1993, p.279). Damage to area V5 is correlated with akinetopsia, a loss of motion sensation (Zihl *et al.* 1983, 1991; Rizzo *et al.* 1995); magnetic inhibition of V5 is also correlated with akinetopsia (Zeki *et al.* 1991). In many tasks in which subjects view a display inducing binocular rivalry, so that they consciously perceive the stimulus presented to one eye and then periodically switch to consciously perceive the stimulus presented to the other eye, there are changes in cortical activity precisely correlated with changes in conscious perception (Alais and Blake 2004), changes that can be measured with fMRI (Lumer *et al.* 1998, Tong *et al.* 1998), EEG (Brown and Norcia 1997), MEG (Tononi *et al.* 1998), and single unit recording (Leopold and Logothetis 1996). Such correlated activity can be found in ventral extrastriate, parietal, and prefrontal cortices (Rees *et al.* 2002).

Such correlations, and many more not mentioned here, persuade most researchers that brain activity causes, or is somehow the basis for, consciousness. As Edelman (2004, p.5) puts it: "There is now a vast amount of empirical evidence to support the idea that consciousness emerges from the organization and operation of the brain." Similarly, Koch (2004, pp. 1–2) argues:

> The fundamental question at the heart of the mind-body problem is, *what is the relation between the conscious mind and the electrochemical interactions in the body that give rise to it?* How do [conscious experiences] emerge from networks of neurons?

Consensus on this point shapes the current scientific statement of the mind-body problem. It is not the neutral statement that opened this section, viz.: What is the relationship between consciousness and biology? Instead, as *Science* makes clear, it is a statement that indicates the expected nature of the solution: What is the biological basis of consciousness? Given this consensus, one would expect that there are promising theories about the biological basis of consciousness, and that research is proceeding to cull and refine them. Indeed such theories are numerous, both philosophical and scientific, and the volume of empirical work, briefly highlighted above, is large and growing.

For instance, following the demise of behaviorism in the 1950s, there have been many philosophical theories. Type physicalist theories assert that mental state types are numerically identical to certain neural state types (Place 1956, Smart 1959); token physicalist theories assert instead that each mental state token is numerically identical to some neural state token (Fodor 1974). Reductive functionalist theories assert that the type identity conditions for mental states refer only to relations, typically causal relations, between inputs, outputs, and each other (Block and Fodor 1972). Non-reductive functionalist theories make the weaker claim that functional relations between inputs, outputs, and internal system states give rise to mental states but are not identical with such states (Chalmers 1996). Representationalist theories (e.g., Tye 1996, 2000) identify conscious experiences with certain tracking relationships, i.e., with certain causal covariations, between brain states and states of the physical world. The "biological naturalism" theory of Searle (1992, 2004) claims that consciousness can be causally reduced to neural processes, but cannot be eliminated and replaced by neural processes.

This brief overview does not, of course, begin to explore these theories, and it omits important positions, such as the emergentism of Broad (1925), the anomalous monism of Davidson (1970), and the supervenience theory of Kim (1993). However it is adequate to make one obvious point. The philosophical theories of the mind-body problem are, as they advertise, philosophical and not scientific. They explore the conceptual possibilities where one might eventually formulate a scientific theory, but they do not themselves formulate scientific theories. The token identity theories, for instance, do not state precisely which neural state tokens are identical to which mental state tokens. The non-reductive functionalist theories do not state precisely which functional relations give rise, say, to the smell of garlic versus the smell of a rose, and do not give principled reasons why, reasons that lead to novel, quantitative predictions. These comments are not, of course, intended as criticisms of these theories, but simply as observations about their intended scope and limits.

It is from the scientists that we expect theories that go beyond statements of conceptual possibilities, theories that predict, from first principles and with quantitative precision, which neural activities or which functional relations cause which conscious experiences. Scientists have produced several theories of consciousness.

For instance, Crick and Koch (1990, cf. Crick 1994) proposed that certain 35-75 Hz neural oscillations in cerebral cortex are the biological basis of consciousness. Subsequently Crick and Koch (2005) proposed that the claustrum may be responsible for the unified nature of conscious experience. Edelman and Tononi (2000, p.144; cf. Tononi and Sporns 2003) proposed that "a group of neurons can contribute directly to conscious experience only if it is part of a distributed functional cluster that, through reentrant interactions in the thalamocortical system, achieves high integration in hundreds of milliseconds." Baars (1988) proposed that consciousness arises from the contents of a global workspace, a sort of blackboard by which various unconscious processors communicate information to the rest of the system. Hameroff and Penrose (1996, cf. Penrose 1994) proposed that quantum coherence and quantum-gravity-induced collapses of wave functions are essential for consciousness. Stapp (1993, 1996) proposed that the brain evolves a superposition of action templates, and the collapse of this superposition gives rise to conscious experience.

Again, this brief overview does not begin to explore these theories and, for brevity, omits some. But the pattern that emerges is clear. The theories so far proposed by scientists are, at best, hints about where to look for a genuine scientific theory. None of them remotely approaches the minimal explanatory power,

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There are several arguments for the absurdity of this claim. First, that chair cannot exist only when I look at it, for I can look away and still touch it. So it still exists. Or, I can look away and you can look at it, and confirm to me that it is still there. So again, it still exists.

But this argument is easily refuted by the virtual-tennis counterexample. Bob can claim that the tennis ball he and Tom are hitting exists even when he does not look at it. After all, he can look away and still touch the tennis ball. Or, he can look away and Tom can look at it. So, Bob can claim, the tennis ball still exists even when he does not look at it. But Bob's claim is patently false.

A second argument: If you think that this train thundering down the tracks is just an icon of your user interface, and does not exist when you do not perceive it, then why don't you step in front of it ? You will soon find out that it is more than an icon. And I will see, after you are gone, that it still exists.

This argument confuses taking something *literally* and taking it *seriously*. If your MUI functions properly, you should take its icons *seriously*, but not *literally*. The point of the icons is to inform your behavior in your niche. Creatures that do not take their well-adapted icons seriously have a pathetic habit of going extinct. The train icon usefully informs your behaviors, including such laudable behaviors as staying off of train-track icons. The MUI theorist is careful about stepping before trains for the same reason that computer users are careful about dragging file icons to the recycle bin.

A third argument: Look, if that wall is just an icon I construct, why can't I walk through it? Shouldn't it do what I want?

Not at all. You construct the subjective Necker cube that you see in Figure 1. But it doesn't do everything you want. For instance, sometimes you see a cube with corner A in front and sometimes a different cube with corner B in front. But try to make yourself switch, at will and instantly, between the two cubes and you will find that your cube constructions are stubborn (for a model of this, see Atmanspacher *et al.* 2004). Or try to see the edges of the cube as wiggly rather than straight. No chance. The fact that we construct our icons does not entail that they do whatever we wish. We are triggered to construct icons by our interactions with the objective world (whatever its nature might be) and, once so triggered, we construct our icons according to certain probabilistic rules (see, e.g., Hoffman 1998). The objective world and our rules for icon construction make the icons stubborn. Still, these icons exist only in our conscious perceptions.

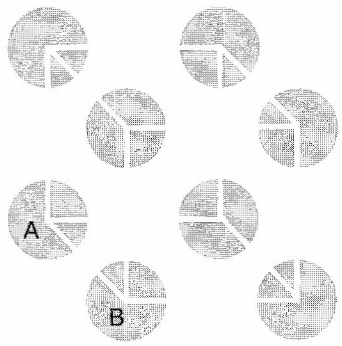

Figure 1: The subjective Necker cube (reproduced from Bradley and Petry 1977).

A fourth argument: Of course tables, chairs, and the moon are just our icons and exist only in our conscious experiences. But what's new? Physicists have long told us that the apparent solidity of a table is an illusion; it is mostly empty space with quarks and leptons darting about. Our perception of a table's surface approximates the envelope of this activity, and in this sense HFD is correct: There are no objective tables, just objective particles.

The mistake here is analogous to a computer user who admits that file icons on the display are just conventional symbols, not the actual files, but then puts a magnifying glass over an icon, sees its pixels, and concludes that these pixels are the actual file. File icons are indeed composed of pixels, but these pixels are part of the interface, not elements of the file. Similarly, tables are indeed composed of quarks and leptons, but quarks and leptons are part of the MUI, not elements of the objective world. The MUI may be hierarchically organized, but different levels of this hierarchy are part of the MUI, not of the objective world.

Placing subatomic particles in the MUI rather than in the objective world is compatible with quantum theory. Indeed, the Copenhagen interpretation of quantum theory asserts that the dynamical properties of such particles have real values only in the act of observation (see, e.g., Albert 1992, Wheeler and Zurek 1983, Zurek 1989). That is, they are part of the observer's MUI. Quantum physics does not contradict MUI theory.

A fifth argument: Ideas similar to MUI theory are found in various forms of idealism. But, as Searle (2004, p.48) says,

> [I]dealism had a prodigious influence in philosophy, literally for centuries, but as far as I can tell it has been as dead as a doornail among nearly all the philosophers whose opinions I respect, for many decades, so I will not say much about it.

This is a simple misunderstanding. MUI theory is not idealism. It does not claim that all that exists are conscious perceptions. It claims that our conscious perceptions need not resemble the objective world, whatever its nature is.

A sixth objection runs as follows: MUI theory implausibly claims that everything we see is not real, but created by an interface between us and the world.

This objection highlights an ambiguity of the word "real." To say that something is real can mean either that it exists, or that it exists independent of any observers. A headache is real in the first sense, but not in the second: If I have a headache, then I am inclined to say that the headache is real and to feel cross with anyone who says otherwise; however, I would not claim that the headache exists independent of me, or that anyone else could experience my headache, or that I could experience the headache of anyone else. Each of us has our own private headaches, and each such headache is real, but entirely dependent for its existence on the observer who has it. I typically have little idea what causes a headache, and therefore little reason to assert that my headache resembles these unknown causes; indeed, it almost surely does not. But the headache is not thereby a mystical veil between me and its unknown causes; instead, it is a simple guide to useful behavior, such as taking an aspirin, and spares me the further headache of ascertaining the complex causes of its genesis.

MUI theory does not claim that everything we see is unreal, but says instead that all sensory perceptions are real in the sense that headaches are real: They exist and are observer-dependent. They exist so long as they are experienced.

This sixth objection also highlights a similar ambiguity of the word "world": This word can refer to a sensory world or to an observer-independent *world*. When we speak of the visual world, we use world in the first sense. The visual world is observer-dependent; it disappears, for instance, when we close our eyes. Similarly, our auditory worlds are silenced if we plug our ears, and our olfactory worlds cease if we pinch the nose. The word "world" can also refer to entities hypothesized to be objective, i.e., to exist independent of any observation. HFD asserts that our sensory worlds resemble or approximate an objective world. MUI theory rejects this assertion.

MUI theory does not claim that our sensory perceptions are created by an interface between us and the world, as in the old sense-datum theories. Instead, MUI theory simply acknowledges that our sensory worlds of space and time, objects, motions, colors, sounds, touches, tastes, smells, and pains are observer-dependent and are not likely, on evolutionary grounds, to resemble the objective world, whatever form that world might have. This point is simple, but can be counterintuitive since we habitually assume, from early childhood, that the objective world resembles our sensory worlds.

A seventh objection is that MUI theory is logically faulty, because it is simply not true that real user interfaces do not imitate the physical world; on the contrary, they do their best to reproduce a physical-like world.

This objection is correct in noting that the user interface on a typical computer employs icons that imitate shapes and colors familiar from everyday sensory perception. However, these icons do not imitate the diodes, resistors, voltages, and magnetic fields inside the computer that they represent. The icons purposely hide all this complexity, so that computer users can get on with their work.

The idea that our sensory perceptions in everyday life are useful precisely because they *do not* resemble what they represent is, for most people, counterintuitive. Fortunately, the recent introduction and widespread popularity of user interfaces on personal computers gives a ready-to-hand metaphor that most can grasp: the typical computer user understands that icons of the interface are useful precisely because they simplify, and in no way resemble, the complex world of hardware and software they represent.

An eighth objection focuses on the notion of resem-

[illegible] as follows: MUI theory recognizes that a virtual replica of the world must share some causality with its target (a virtual tennis ball must behave causally like the real one, more or less). However MUI theory does not see that this is a kind of isomorphism between the world and the user interface. It seems to consider only pictorial isomorphisms as relevant. This is not the case.

This objection is correct in noting that a tennis ball in a realistic virtual-reality game behaves much like a normal tennis ball. But the point of the virtual-reality example is not the relation between virtual tennis balls and normal tennis balls, but rather the relation between virtual tennis balls and supercomputers. The point is that the virtual tennis ball in no way resembles, pictorially or otherwise, the structural or causal properties of the supercomputer that is running the virtual tennis game. Then, by analogy, the reader is invited to envision the possibility that a *normal* tennis ball might in no way resemble, pictorially or otherwise, the structural or causal properties of whatever observer-independent entities it represents.

So the analogy offered here is as follows: Virtual tennis ball is to supercomputer as normal tennis ball is to the observer-independent world. The supercomputer is vastly more complex, structurally and causally, than a virtual tennis ball; the observer-independent world is, in all likelihood, vastly more complex, structurally and causally, than a normal tennis ball. In mathematical terms, the functions relating the supercomputer to the virtual tennis ball, or the observer-independent world to the normal tennis ball, are not isomorphisms or bijections, but are instead many-to-one maps that lose much information.

A ninth objection questions the entire metaphor of virtual reality: The whole issue of virtual reality is dependent on the creation of real stimuli (for instance, a head-mounted display projects real lights and real colors to the subject's head). There is no evidence about the possibility of creating a super virtual-reality world (like that in the *Matrix* movie). There is no empirical ground on which an argument can be built.

The evidence that our sensory worlds *might* be virtual worlds that in no way resemble an observer-independent world comes from quantum physics. There are many interpretations of quantum theory, and this is no place to enumerate them. Suffice it to say that proponents of the standard interpretation (the Copenhagen interpretation) often respond to the empirical evidence for quantum entanglement and violation of Bell's inequalities by rejecting local realism, and in particular by claiming that definite physical properties of a system do not exist prior to being observed; what does exist in observer-independent reality is, on their view, unknown. Which definite physical properties are instantiated at any instant depends entirely on how and what we choose to observe, i.e., on the particular observables we choose. If we choose to observe momentum, we get a value of momentum. But this value did not exist before we observed, and ceases to exist if we next choose to measure, say, position.

Thus, the possibility that our sensory worlds *might* be virtual worlds, akin to a user interface, comports well with the empirical evidence of quantum physics and is endorsed by some physicists. This is not to say, of course, that quantum theory *requires* this interpretation. Proponents of decoherence approaches, for instance, reject this interpretation. And most proponents of the Copenhagen interpretation embrace it only for the microscopic realm, not the macroscopic, but this saddles them with the unsolved problem of providing a principled distinction between microscopic and macroscopic.

6. Conscious Realism

MUI theory, we have seen, makes no claim about the nature of the objective world. In this section, I propose a theory that does: conscious realism. One could accept MUI theory and reject conscious realism. But they fit well, and together provide a novel solution to the mind-body problem. Conscious realism is a proposed answer to the question of what the universe is made of. Conscious realism asserts that the objective world, i.e., the world whose existence does not depend on the perceptions of a particular observer, consists entirely of conscious agents.

Conscious realism is a non-physicalist monism: What exists in the objective world, independent of my perceptions, is a world of conscious agents, not a world of unconscious particles and fields. Those particles and fields are icons in the MUIs of conscious agents, but are not themselves fundamental denizens of the objective world. Consciousness is fundamental. It is not a latecomer in the evolutionary history of the universe, arising from complex interactions of unconscious matter and fields. Consciousness is first; matter and fields depend on it for their very existence. So the terms "matter" and "consciousness" function differently for the conscious realist than they do for the physicalist. For the physicalist, matter and other physical properties are ontologically fundamental; consciousness is derivative, arising from or identified with complex interactions of matter. For the conscious realist, consciousness is ontologically fundamental; matter is derivative and among the symbols constructed by conscious agents.

According to conscious realism, when I see a table, I interact with a system, or systems, of conscious agents, and represent that interaction in my conscious experience as a table icon. Admittedly, the table gives me little insight into those conscious agents and their dynamics. The table is a dumbed-down icon, adapted to my needs as a member of a species in a particular niche, but not necessarily adapted to give me insight into the true nature of the objective world that triggers my construction of the table icon. When, however, I see you, I again interact with a conscious agent, or a system of conscious agents. And here my icons give deeper insight into the objective world: they convey that I am, in fact, interacting with a conscious agent, namely you.

Conscious realism is not panpsychism; nor does it entail panpsychism. Panpsychism claims that all objects, from tables and chairs to the sun and moon, are themselves conscious (Hartshorne 1937/1968, Whitehead 1929/1979), or that many objects, such as trees and atoms, but perhaps not tables and chairs, are conscious (Griffin 1998). Conscious realism, together with MUI theory, claims that tables and chairs are icons in the MUIs of conscious agents, and thus that they are conscious experiences of those agents. It does not claim, nor entail, that tables and chairs are conscious or conscious agents. By comparison, to claim, in the virtual-tennis example, that a supercomputer is the objective reality behind a tennis-ball icon is not to claim that the tennis-ball icon is itself a supercomputer. The former claim is, for purposes of the example, true, but the latter is clearly false.

Conscious realism is not the transcendental idealism of Kant (1781/2003). Exegesis of Kant is notoriously difficult and controversial. The standard interpretation has him claiming, as Strawson (1966, p.38) puts it, that "reality is supersensible and that we can have no knowledge of it." We cannot know or describe objects as they are in themselves, the noumenal objects; we can only know objects as they appear to us, the phenomenal objects (see also Prichard 1909). This interpretation of Kant precludes any science of the noumenal, for if we cannot describe the noumenal then we cannot build scientific theories of it. Conscious realism, by contrast, offers a scientific theory of the noumenal, viz., a mathematical formulation of conscious agents and their dynamical interactions. This difference between Kant and conscious realism is, for the scientist, fundamental. It is the difference between doing science and not doing science. This fundamental difference also holds for other interpretations of Kant, such as that of Allison (1983).

Many interpretations of Kant have him claiming that the sun and planets, tables and chairs, are not mind-independent, but depend for their existence on our perception. With this claim of Kant, conscious realism and MUI theory agree. Of course, many current theorists disagree. For instance, Stroud (2000, p.196), discussing Kant, says:

> It is not easy to accept, or even to understand, this philosophical theory. Accepting it presumably means believing that the sun and the planets and the mountains on earth and everything else that has been here so much longer than we have are nonetheless in some way or other dependent on the possibility of human thought and experience. What we thought was an independent world would turn out on this view not to be fully independent after all. It is difficult, to say the least, to understand a way in which that could be true.

But it is straightforward to understand a way in which that could be true. There is indeed something that has been here so much longer than we have, but that something is not the sun and the planets and the mountains on earth. It is dynamical systems of interacting conscious agents. The sun and planets and mountains are simply icons of our MUI that we are triggered to construct when we interact with these dynamical systems. The sun you see is a momentary icon, constructed on the fly each time you experience it. Your sun icon does not match or approximate the objective reality that triggers you to construct a sun icon. It is a species-specific adaptation, a quick and dirty guide, not an insight into the objective nature of the world.

One reader commented that conscious realism and MUI theory entail not just that the objects of our experience are created by subjects, but also that particles and all the rest are so created. Eventually the theory will claim that natural selection and time are a creation of the user interface. It is more noumenic than Kant.

This comment is correct, *pace* Kant. Space, time, particles, and therefore natural selection are all within the user interface. But this claim comports well with recent attempts in physics to construct a theory of everything – including space, time, and particles – from more fundamental constituents, such as quantum information and quantum computing (e.g., Lloyd 2006), loop quantum gravity (Smolin 2006), and others (e.g., Callender and Huggett 2001). Space-time, classically conceived as a smooth manifold, appears untenable at the Planck scale. Instead, there appear to be "pixels" of space and time. The intuition that space-time is a fundamental constituent of an observer-independent reality seems destined to be overturned by theories of quantum gravity.

The ontology of conscious realism proposed here rests crucially on the notion of conscious agents. This notion can be made mathematically precise and yields experimental predictions (Bennett *et al.* 1989, 1991; Bennett *et al.* 1993a,b; Bennett *et al.* 1996). Space precludes presenting the mathematics here, but a few implications of the definition of conscious agent should be made explicit. First, a conscious agent is not necessarily a person. All persons are conscious agents, or heterarchies of conscious agents, but not all conscious agents are persons. Second, the experiences of a given conscious agent might be utterly alien to us; they may constitute a modality of experience no human has imagined, much less experienced. Third, the dynamics of conscious agents do not, in general, take place in ordinary four-dimensional space-time. They take place in state spaces of conscious observers, and for these state spaces the notion of dimension might not even be well-defined. Certain conscious agents might employ a four-dimensional space-time as part of their MUI, but, again, this is not necessary.

From these comments, it should be clear that the definition of a conscious agent is quite broad in scope. Indeed, it plays the same role for the field of consciousness that the notion of a Turing machine plays for the field of computation (Bennett *et al.* 1989).

7. The Mind-Body Problem

We now use MUI theory and conscious realism to sketch a solution to the mind-body problem. Exactly what that problem is depends, of course, on one's assumptions. If one adopts *physicalism*, then the central scientific problem is to describe precisely how conscious experience arises from, or is identical to, certain types of physical systems.

As we discussed before, there are no scientific theories of the physicalist mind-body problem. If one adopts *conscious realism*, then the central mind-body problem is to describe precisely how conscious agents construct physical objects and their properties.

Here there is good news; We have substantial progress on the mind-body problem under conscious realism, and there are real scientific theories. We now have mathematically precise theories about how one type of conscious agent, namely human observers, might construct the visual shapes, colors, textures, and motions of objects (see, e.g., Hoffman 1998; Knill and Richards 1996, Palmer 1999).

One example is Ullman's (1979) theory of the construction of three-dimensional objects from image motion. This theory is mathematically precise and allows one to build computer-vision systems that simulate the construction of such objects. There are many other mathematically precise theories and algorithms for how human observers could, in principle, construct three-dimensional objects from various types of image motions (e.g., Faugeras and Maybank 1990, Hoffman and Bennett 1986, Hoffman and Flinchbaugh 1982, Huang and Lee, 1989, Koenderink and van Doorn 1991, Longuet-Higgins and Prazdny 1980). We also have precise theories for constructing three-dimensional objects from stereo (Geiger et al. 1995, Grimson 1981, Marr and Poggio 1979), shading (Horn and Brooks 1989), and texture (Aloimonos and Swain 1988, Witkin 1981). Researchers debate the empirical adequacy of each such theory as a model of human perception, but this is just normal science.

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ments of Cognitive Science, Computer Science, and Philosophy. He is author of the book Visual Intelligence: How We Create What We See *(W.W. Norton, 2000), and coauthor of the book* Automotive Lighting and Human Vision *(Springer, 2007). His research on cognitive neuroscience and human visual perception received a Distinguished Scientific Award from the American Psychological Association and the Troland Research Award of the U.S. National Academy of Sciences.*

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Remote Viewing Mind Puzzle
(ANSWERS)

Down

1. Stargate
2. Matrix
4. Aperture
8. Coordinate
9. HemiSync
11. Jung
12. SRI
13. AOL
14. Targ
17. Dowsing

Across

3. Ideogram
5. CRV
6. Sensory
7. Pat Price
10. Fort Meade
12. Signal Line
15. Swann
16. Bilocation
18. Outbounder
19. Sketch

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