Introduction

Science is a crowning glory of the human spirit and its applications remain our best hope for social progress. But there are limitations to current science and perhaps to any science. The general mind-body problem is known to be intractable and currently mysterious. This is one of many deep problems that are universally agreed to be beyond the current purview of Science, including quantum phenomena, etc. But all of these famous unsolved problems are either remote from everyday experience (entanglement, dark matter) or are hard to even define sharply (phenomenology, free will, etc.).

In this note, we will consider some obvious computational problems in vision that arise every time that we open our eyes and yet are demonstrably incompatible with current Neuroscience. The focus will be on two related phenomena, known as the neural binding problem and the illusion of a stable visual world. I, among many others, have struggled with these issues for more than fifty years (1, 2, 3) and I now believe that they are both unsolvable within current science. By considering some basic facts about how the brain processes image input, we will show that there are not nearly enough brain neurons to compute what we experience as vision. I suggest that these facts should induce skepticism and humility about the prospects for current science to yield a complete reductionist account of even concrete aspects of vision and other thought processes. More concretely, the demonstrations below suggest possible new models and experiments.

Demonstrations

The visual system can only see fine detail in a small (~1 degree) part of the visual field; this is about the size of your thumbnail at arm’s length. “The Illusion of a detailed full-field stable visual world” refers to our subjective perception of a large high-resolution scene. Let’s first consider Figure 1. As you know, your vision is best in the center of gaze and the small letters in the center of the figure are easy to read when you look directly at them, but not when you look to the side. The letters away from the center are progressively larger and this describes how much coarser your vision becomes with eccentricity.

Figure 1. Size for Equal Visibility with Eccentricity
You can experience this directly using the line of text in Figure 2. Cover or close one eye and focus on the x in the center from a distance of about 12 inches. While holding focus, try to clearly see the letters to the left. You should be able to do much better with the progressively larger letters to the right of the x.

Figure 2.

More generally, representing more information requires more hardware, which is why new phones are marketed as having cameras with more megapixels. This is also believed to be true for the neurons in the brain. There is a great deal known about how the brain processes visual information, largely because other mammals, particularly primates, have quite similar visual systems. We will focus on what is called primary visual cortex or V1. Looking ahead, Figure 4B shows a flattened and projected view of the human brain with V1 on the far left.

Unsurprisingly, the brain realizes this high central resolution using many, densely packed, neurons. The central portion of the retina in the eye is called the fovea and the downstream target of these foveal neurons in V1 of the brain is called the foveal projection.

Figure 3. Tootell Experiment (4)

An important aspect of this architecture can be seen in Figure 3. The upper part of the figure depicts an oscillating radial stimulus, also with more detail in the center, which was presented to a primate subject. The lower half of the figure shows the parts of visual cortex that responded strongly to the input. As you can see, by far the most activity is the foveal projection on the far left, corresponding to the detailed image in the center of the input stimulus (red arrow). So, vision is most accurate in a small central area of the visual field and this is achieved by densely packed neurons in the corresponding areas of the brain (4).
But our visual experience is not at all like this. We see the world as fully detailed and there is currently no scientific explanation of this. But there is more - we normally move (saccade) our gaze to new places in the scene about 3 or 4 times per second. These saccades help us see and act effectively and are not random. But again, our experience does not normally include any awareness of the saccades or the radically different visual inputs that they entail. Taken together these unknown links between brain and experience are known as “the illusion of a detailed stable visual world” and this is universally accepted, if not understood.

There is extensive continuing research on various aspects of visual stability (6, 7, 8, 9, 10, 11). None of this work attempts to provide a complete solution and it is usually explicit that deep mysteries remain. Reference 9 is an excellent survey of behavioral findings and reference 11 has current neuroscience results.

We are attempting here to establish a much stronger statement. These stable world phenomena and a number of others are inconsistent with current science. The demonstrations below require combining findings from several distinct areas of investigation, as an instance of Unified Cognitive Science (12). There is always the possibility of a conceptual breakthrough, but it would entail abandoning some of our core beliefs about (at least) neural computation.

The basic form of the argument will be computational. There is no way that brain neurons, as we know them, could represent or compute the substrate of our visual experience. To explore the details, we turn next to Figure 4 A, B.

Figure 4 Flat map projection of the Human brain (5)

Figure 4A is a standard flattened projection of one hemisphere of the human brain with the various areas colored. The numbers refer to the traditional Brodmann classification of brain regions from their anatomical details. Modern methods have further refined this picture and elaborated the basic functions computed in different areas. Figure 4B provides more detail on the functional separation in the visual system, which is the core of the neural binding problem, one of our mysteries.

The visual area V1, our main concern for the stable world illusion and the subject of Figure 3, is shown as the yellow area on the left of Figure 4A (as area 17) and as the cyan area in Figure 4B. Notice that V1 is by far the largest of the visual areas; this will be important for our discussion.
There are two additional lessons to be gleaned from Figure 4 above. First of all, 4A shows that the functionality of the cerebral cortex is basically known (5) – there is no large available space for neural computation of currently mysterious phenomena. Also, various aspects of our visual experience are primarily computed in distinct and often distant circuits. For example, color calculation is based in the bright green area V4v and motion calculation involves several areas: V3, V3A, MT, etc. In spite of this extreme separation of function, we see the world as an integrated image with objects that combine all visual properties and even associate these with other senses like sound when appropriate. The mystery of how this happens is called the “hard binding problem” (3).

**Computational Limitations**

There are two immediate challenges to address in “the illusion of the stable visual world”: apparent stability over saccades and the detailed perception of the full visual field. One popular idea is to suppose that the perceived full field is pieced together as a mosaic of “bull’s-eye” views (Figure 3) from many saccades. There are two serious flaws in this story, one temporal and one spatial, as an explanation of the illusion. We only make about 3~4 saccades per second – this is too slow for stable vision (movies are ~ 20 frames per second). Also 3 or 4 such images would not yield nearly enough detailed information to build a detailed full field view.

In addition, it would require a huge area of visual neurons to encode the detailed full field view that we subjectively perceive. We can give a quantitative estimate of what is involved. Multiple calculations in the literature are in close agreement:

Overall, there are approximately 160 times more striate cells per cone in the fovea than in the periphery. Thus, the surface area of primary visual cortex would have to be increased by a factor of roughly 13 (Sqrt 160) to support peripheral sampling as fine as that of the fovea. (13). The dense neural circuits in the V1 foveal projection has about 200,000 cells per square mm, while at 20 degrees out it is more like 4,000 cells per square mm (15). This is a factor of 50:1 denser in the V1 fovea than in the periphery. The V1 foveal projection occupies about a quarter of region on the left in Figure 4. For the brain to encode our detailed perception out to 20 degrees would require an area roughly 12 times the size of V1. There is no way that an area nearly this large could fit into Figure 4.

We can also consider the evidence from the hundreds of full-brain scanning experiments that are exploring which brain locations are active for various vision tasks (16, 17, 18). This precludes the possibility that a network large enough to capture a detailed image could remain undetected.

In summary, as long as we believe that more detail requires more neurons, there is no place in the brain that could encode a basis for the detailed large field image that we perceive. This analysis not only disproves the idea of unknown brain circuitry that underlies our stable world illusion. It also refutes any plausible substrate for other proposals such as complete “remapping” which suggest that all of the information from one saccade is (somehow) mapped to the input coming from the next saccade (7, p.557).

The binding problem is a closely related mystery of vision that we should consider, also based on Figure 4. Although the full computational story is more complex, it is basically the case that different visual features are largely computed in separate brain areas. The problem is that we experience the world as coherent entities combining various properties such as size, shape, color, texture, motion, etc. As before, there is no place in the brain that could
encode a detailed substrate for what we effortlessly perceive. This also suggests that our subjective perception (somehow) integrates activity from different brain circuits. Various forms of the binding problem are also the subject of ongoing research (3,19).

There is a plausible functional story for the stable world illusion and feature binding. First of all, we do have an integrated (top-down) sense of the space around us that we cannot currently see, based on memory and other sense data – primarily hearing and smell. Also, since we are heavily visual, it is adaptive to use vision as broadly as possible. In fact, it would be extremely difficult to act in the world using only the bulls-eye images from Figure 1 and separated information on size, color, etc. But this functional story tells us nothing about the neural mechanisms that support this magic.

**A Touchstone for alternative brain theories**

The discussion above is based on the standard theory that information processing in the brain is based on complex networks of neurons that communicate mainly by electrical spikes and learn mainly through changes in the connections (synapses) between neurons. This theory also includes a wide range of other chemical and developmental factors, but none that would affect the basic results above.

However, there are a number of radical proposals that deny the centrality of neural computation and several of these are being actively discussed (20); a good source for a wide range of alternative models is [http://consciousness.arizona.edu](http://consciousness.arizona.edu). One reason for this is that everyone agrees that the standard model does not currently support a reductionist explanation of historic mind-brain problems like subjective experience and consciousness.

Alternative ideas on the basis for brain information processing include quantum effects and central roles for the glia, for the neuropil, or for microtubules. More general architectural suggestions include a globalworkspace model and the Tononi information model (20). Many proposals suggest some unspecified mass action of neural assemblies, following a long tradition (21). Since the deep mind-brain phenomena of most interest are not well defined, it has not been straightforward to evaluate any of these suggested alternatives to the standard model of neural computation.

The findings described above could yield concrete touchstone problems for proposed theories of representation, computation, and communication in the brain. Both the binding problem and the illusion of a detailed stable visual scene are ubiquitous in daily experience and have clear informational requirements. We could ask proponents of speculative brain models how their theory could account for these two concrete phenomena. That is, assume your theory is true and show how it explains these (or other) touchstone problems. I have done this informally with several leading proponents of alternative models and have never heard even a vague claim of adequacy. The general acceptance of some such touchstone tasks could sharpen the discussion of information processing in the brain. Of course, the deep mind-brain problem remains a mystery, but we could require that proposed models of neural computation address some of the concrete touchstone problems.

**Conclusions**

There is general agreement that there are mysteries about the world and our place in it that are not yet understood. Even radical materialists will concede that there are questions (e.g. free will) that might never have scientific solutions. But it is not widely understood that, every
time we open our eyes, we experience phenomena that cannot be explained with current science and possibly not with any science.

As thinkers we have no choice but to acknowledge that we do not know and may never know the answers to many deep questions about the world and ourselves. There are two basic ways to learn about the world, investigation and stories. Science is a uniquely powerful social tool of investigation, but is limited in scope at least at present. Of course, there remains a vast amount that can and should be explored and exploited scientifically. Stories can provide insights that are not directly testable, and this is certainly also important in science. The stories in art, mythology, religion, etc. have been and will remain powerful sources of insights about how to live.

Everyone is entitled to their own (religious or other) beliefs, but there is nothing about our current ignorance that privileges one faith over all others. Belief in the inevitability of complete scientific answers is one such faith. There are beliefs (e.g. about the age of the Earth) that contradict established scientific knowledge and cannot be taken seriously. But in the face of all that is unknown, we do well to appreciate both what is scientifically known and also the irreducible mysteries that remain. Ideally, results like those above will encourage theory and experiment on questions at the boundaries between the known and unknown.

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References


