Causality in the Sciences
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The autonomy of psychology in the age of neuroscience

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Abstract and Keywords

The implications of multiple realization for scientific methodology have recently been hotly debated. For example, neuroscientists have discovered distinct realizations for what appears to be a single psychological property and some philosophers have recently maintained that in such cases scientists will always abandon commitment to the single, multiply realized psychological property in favour of two, or more, uniquely realized psychological properties. This chapter explores such methodological claims by building on the dimensioned theory of realization and a companion theory of multiple realization. Using concrete cases, this chapter shows that such an 'eliminate-and-split' methodology is not always the case in actual practice. Furthermore, this chapter also establishes that whether scientists postulate unique or multiple realizations is not determined by the neuroscience alone, but only in concert with the psychological theory under examination. Thus, in a sense this chapter articulates, in the splitting or non-splitting of properties, psychology enjoys a kind of autonomy from neuroscience.

Keywords: realization, multiple realization, methodology, dimensioned view of realization, human color vision

Abstract

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philosophers have recently maintained that in such cases scientists will always abandon commitment to the single, multiply realized psychological property in favour of two, or more, uniquely realized psychological properties. In this chapter, we explore such methodological claims by building on the dimensioned theory of realization and a companion theory of multiple realization. Using concrete cases, we show that such an ‘eliminate-and-split’ methodology is not always the case in actual practice. Furthermore, we also establish that whether scientists postulate unique or multiple realizations is not determined by the neuroscience alone, but only in concert with the psychological theory under examination. Thus, in a sense we articulate, in the splitting or non-splitting of properties, psychology enjoys a kind of autonomy from neuroscience.

Suppose that scientists discover a high level property G that is *prima facie* multiply realized by two sets of lower level properties, F_1, F_2,…, F_n, and $F^*_1, F^*_2, \ldots, F^*_m$. One response would be to take this situation at face value and conclude that G is in fact so multiply realized. A second response, however, would be to eliminate the property G and instead hypothesize subtypes of G, G_1 and G_2, and say that G_1 is uniquely realized by F_1, F_2,…, F_n, and that G_2 is uniquely realized by $F^*_1, F^*_2, \ldots, F^*_m$. This second response would eliminate a multiply realized property in favour of two uniquely realized properties.[1]

Clearly these are two logically possible responses to this type of situation, so when faced with it how do scientists respond in real cases? This is a matter of providing a descriptively adequate account of actual scientific practice. In support of the view that scientists opt for the ‘eliminate-and-split’ strategy, one might propose that it is illustrated by the way scientists responded in the **(p. 203)** case of memory. Once upon a time, it was thought that there existed a single kind of memory. With the advance of science, however, it was discovered that it is possible to perform certain sorts of brain lesions that would lead to the selective loss of certain memory functions, while certain other sorts of brain lesions would lead to selective loss of certain other memory functions. These neurobiological dissociation experiments, one might say, support the view that, instead of a single overarching type of memory, there are distinct subtypes of memory, procedural memory and declarative memory. Thus, generalizing from this example, it might be suggested that the eliminate-and-split strategy is always the approach of scientists in such cases.

We believe that this argument is based upon serious oversimplifications. To begin with, note that there is the assumption that scientists treat all discoveries about differences in realizers in the same way. We contend, however, that actual practice is far more complicated than this. For one thing, realistic biological and psychological cases typically have a greater diversity of lower realizing properties than is commonly appreciated. Consequently, discoveries about differences in lower level realizers might be expected to interact in a variety of different ways with the higher level realized properties. Once we take this last possibility seriously, we contend that one finds that in actual scientific practice not all discoveries about differences in realizing properties influence higher level theory in the same way. In particular, scientists do not uniformly adopt the eliminate-and-split strategy. As we show by reference to actual examples, discoveries about different lower level realizers *are* handled in different ways depending upon the nature of the higher level theory.

By considering actual cases, we show that finding variations in some lower level realizers, say, F_1, F_2, …F_i, sometimes leads scientists to posit differences in the higher level realized property G, thus following the eliminate-and-split strategy. But in other cases even though scientists find variation in other realizers, say F_j, …, F_n, such differences do not lead the scientists to posit differences in higher level properties. To speak somewhat metaphorically, we might label the former sort of realizers ‘parallel realizers’, since findings about differences in the lower level realizers give rise to scientists positing parallel differences in our theories about the higher level realized property. We might then label the latter sort of realizers ‘orthogonal realizers’ because differences among them do not lead researchers to change their theories about the higher level property. The idea behind the name for these realizers is, therefore, that differences among them are, in some sense, orthogonal to the higher level account. Such examples show that scientists do not simply follow an eliminate-and-split strategy. Perhaps more importantly, these cases show that, although psychology takes account of neuroscience, the details of *how* it does this are determined by the needs of psychological theorizing in partnership with lower level theories.

(p. 204) Our cases also reveal that even the distinction between cases involving parallel and orthogonal realizers fails to do justice to all the nuances of actual scientific practice. For we show that in some cases in biology and psychology, discoveries about differences in lower level realizers lead scientists to posit what they term ‘individual differences’ in the *same* higher level property of subjects. These examples indicate that even the distinction between orthogonal and parallel realizers needs to be amended in still further ways. On the one hand, the realizers that give rise to individual difference are not orthogonal realizers, since discoveries about variations in them does lead to changes in our higher level theories about the realized properties. But, on the other hand, the realizers that give rise to individual differences affect higher level theories about realized properties in a manner distinct from the eliminate-and-split strategy. For scientists continue to posit the same higher level property, though distinguishing variations within it. We therefore also distinguish between two kinds of parallel realizers, ‘strong’ and ‘weak’, in the following ways. We have *strong* parallel realizers in cases where differences in these realizers prompt scientists to eliminate the original realized property and posit distinct realized properties for the different realizers. Thus strong parallel realizers underpin the eliminate-and-split approach. However, we also sometimes have weak parallel realizers in examples where the variations in realizers do prompt revisions in our higher level accounts about the realized property, but where scientists posit individual differences within the same realized property.

Even when variations in realizers prompt changes in our higher level theories, we show that such revisions do not always follow the eliminate-and-split model. Once again, we also show that the nature of the higher level theory plays a key role in whether scientists take parallel realizers to be weak or strong. Thus the autonomy of psychology in the age of neuroscience is, in part, a kind of methodological, rather than ontological autonomy. Psychological theory shapes how psychology accommodates the discovery of differences in neuroscientific realizers in partnership with lower level theories, rather than the lower level theories simply necessarily dictating changes through their discoveries.

Throughout the chapter we focus directly upon the case of properties and their instances, but our work has obvious consequences for causal processes and our theorizing about them. Like most other writers in the metaphysics of science we endorse the causal theory of properties and take properties to be individuated by their contributions of powers.[2] Putting things crudely, processes in the sciences are grounded by the manifestation of the powers contributed to individuals by such properties and we therefore plausibly have **(p. 205)** different kinds of process where we have different properties and powers. Consequently, competing views over the implications of discoveries about multiple realization for the diversity of higher level properties also have implications for the diversity of higher level processes, too. For example, the eliminate-and-split strategy entails that we increase the kinds of higher level process we accept when we discover cases of multiple realization, since it claims we increase the number of higher level properties we posit. Although we do not explicitly focus on the implications for processes, our critical work therefore also shows that such claims about higher level processes are also too simple and too quick because they fail to reflect the nuances of actual practices.

To articulate and defend these views, in Section 10.1 we briefly review the dimensioned view of realization and a theory of multiple realization that naturally and elegantly accompanies it. The remainder of the chapter then draws attention to the ways in which current scientific research treats the properties of the eye that realize normal human colour vision. This research is extremely useful for the study of realization and multiple realization, since scientists have a relatively firm grasp of the natures of both realizer and realized properties at multiple levels. Section 10.2 reviews some of the basic features of colour processing in the eye. This sets the stage for Section 10.3 where we consider three examples from the sciences that illuminate the various ways in which discoveries concerning lower level realizers do, or do not, influence the properties postulated in higher levels. Finally, Section 10.4 examines the realization of procedural and declarative memory as analysed by Craver (2004) and shows how the morals developed in the preceding sections bear on this example.

10.1 The dimensioned view of realization and a theory of multiple realization

As the dimensioned view of realization and its companion theory of multiple realization have been described and defended in detail in numerous other publications, only a brief review of them will be presented here.[3] The core idea of the dimensioned view of realization is that, typically, many lower level property instances will together realize an instance of a higher level property. The official statement of the view is that **(p. 206)**

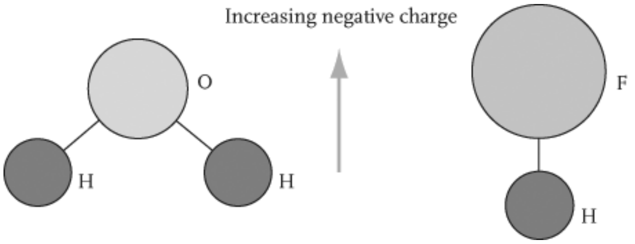

Fig. 10.1 The polarity of water and hydrogen fluoride.

> Property/relation instance(s) F_1–F_n realize an instance of a property G, in an individual *s* under conditions $, *if and only if*, under $, F_{1-n} together contribute powers, to *s* or *s*'s part(s)/constituent(s), in virtue of which *s* has powers that are individuative of an instance of G, but not vice versa.

So, to take a very simple example from chemistry, let s be an individual water molecule with the property G of being polar, i.e. more negatively charged in one direction than in another. (See Figure 10.1.) What makes a water molecule polar? It has to do with the greater electronegativity of oxygen versus hydrogen along with the angle of the bond between the two hydrogen atoms and the oxygen atom. The two instances of the hydrogen's electronegativity of 2.2 on the Pauling scale, the one instance of the oxygen's electronegativity of 3.44 on the Pauling scale, and the bond angle of 105° between the two hydrogen bonds leads electrons to cluster nearer the oxygen atom, hence for the 'oxygen side' of the molecule to be more negative where the 'hydrogen side' of the molecule is more positive. These facts can be inserted in the schema above in the obvious way.[4]

The core idea of multiple realization is that one must have instances of one set of properties F_1–$F_n$that realizes an instance of G and another set of instances of distinct properties

$$F^*_1 - F^*_m$$

that realizes another instance of G and that these properties are not identical.[5] Things are not *that* simple, however, since one does not count the realization of, say, pain at the neuronal level and at the biochemical level as multiple realizations of pain. One must add that **(p. 207)** the two distinct realizers that multiply realize G must be at the same level. The official formulation of multiple realization is, therefore, that

> A property G is multiply realized *if and only if* (i) under condition $, an individual *s* has an instance of property G in virtue of the powers contributed by instances of properties/

> relations F_1–$F_n$to *s*, or s's constituents, but not vice versa; (ii) under condition $* (which may or may not be identical to $), an individual *s** (which may or may not be identical to s) has an instance of property G in virtue of the powers contributed by instances of properties/relations
> $F^*_1 - F^*_m$
> of *s** or *s**'s constituents, but not vice versa; (iii)
> $F_1 - F_n \neq F^*_1 - F^*_m$
> and (iv), under conditions $ and $*, F_1–F_n of *s* and
> $F^*_1 - F^*_m$
> of *s** are at the same scientific level of properties.

To continue with the example of polarity, we can explain how it is multiply realized. A water molecule has this property in virtue of the electronegativity of the hydrogen and oxygen atoms and the angle at which they are bonded. A hydrogen fluoride molecule, however, is polar in virtue of the hydrogen's electronegativity, fluorine's electronegativity, and the bond between them. (See Figure 10.1.)

Of the many important features of the dimensioned view, the one that will be most important for the present discussion of multiple realization and the possible elimination and subtyping of properties is the fact that there are typically many distinct lower level realizers F_1–F_n for a single higher level property instance G. Once we begin to examine actual scientific cases with this in mind we recognize the possibility of different ways in which higher level theory can handle discoveries about different lower level realizers. Sometimes different sets of lower level realizers may still result in the very same higher level property. Other times, different sets of lower level realizers may prompt recognition of individual differences across instances of the same higher level realized property. While still other lower level differences may be such that they force us to say that these realizers actually result in different realized properties. What we will see is that one subset of realizers, F_1F_gwill be handled one way, another subset F_h–F_j will be handled in another, and still another subset, F_k–F_n will be handled in yet another, depending upon features of the higher level theory. Sometimes differences in realizers together result in instances of the same realized property–perhaps with individual differences across these instances–and sometimes they together result in instances of distinct realized properties.

10.2 The mechanisms of colour vision in the eye

The mechanisms of colour vision are realized in many regions of the body and the central nervous system, including the eye, the lateral geniculate nucleus, areas V1, V2, V4, and likely very many more. Our present philosophical **(p. 208)** concerns will, however, be best served by limiting our attention to the mechanisms within the eye. Insofar as there is realization and multiple realization of colour vision by the apparatus of the eye, there will be at least that much realization and multiple realization in the entirety of the visual system.

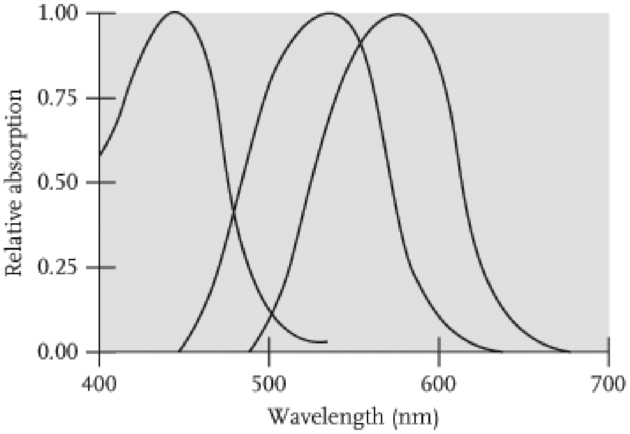

Fig. 10.2 Photopigment absorption curves.

If we begin at the level of the entire eye, we can say that the visual system begins to interact with light as soon as photons enter the cornea. Since the cornea, aqueous humor, lens, and so forth, are not perfectly transparent, these components influence the retina's response to incoming light. Moreover, since they do not absorb all wavelengths of light equally, they change the spectral distribution of incoming light, hence the colour that a person perceives. The pre-receptoral components of the eye that absorb most of the incoming light are the lens and the macular region of the eye (which contains the vast majority of the colour processing cones of the eye). What will matter for us is the fact that an eye's response to light depends on three distinct components: the lens, the macula, and the photoreceptors.

If we descend to the level of the retina, we naturally turn our attention to the colour photoreceptors, the cones. On the standard trichromatic theory of human colour vision, the ability to perceive colour is based on making comparisons of signals from three distinct types of cones–red, green, and blue–each sensitive to a slightly different range of the visible spectrum of electromagnetic radiation.[6] (See Figure 10.2.) It is well known that abnormalities in the cones can lead to abnormalities in colour perception. Protanopes lack red **(p. 209)** cones and deuteranopes lack green cones. They, therefore, perceive the visible spectrum of light differently than do those with normal colour vision.

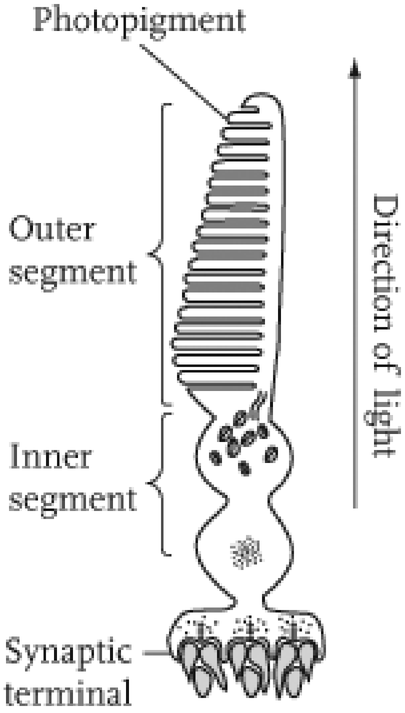

Fig. 10.3 Human cone.

Moving to the cellular level, we discover that each cone has photopigment molecules embedded in the membrane of its outer segment. (See Figure 10.4.) Each cone's photosensitivity is determined by three principal factors: the length of the cone's outer segment, the concentration of the photopigment in the outer segment, and the sensitivity of the individual photopigment molecules. These first two features involve relatively pedestrian physics, but the final one concerns the biochemistry of photopigments, a topic of significant interest in the sciences of colour vision.

At the biochemical level, a given photopigment molecule consists of a protein component–a red, green, or blue cone opsin–and a non-protein component–an 11–*cis*-retinal chromophore. The chromophore component of a photopigment is responsible for the actual process of photon capture and is the same in all photopigments, where the opsin component modulates the frequencies of light to which the chromophore is sensitive. Differences in the amino acid sequences of the normal red, green, and blue cone opsins, thus give rise to the differences in light sensitivity of the complete photopigment molecules.

As our final bit of scientific information on human colour vision, we note that the photopigments are only one component in the biochemical cascade that links photon capture to neuronal signaling. (See Figure 10.3.) Upon absorption of a photon, a single photopigment molecule will change conformation from 11–*cis*– retinal to all-*trans*-retinal. After this conformational change, the retinal chromophore is released and the opsin molecule is activated. The activated opsin binds to a single G protein molecule located on the inner surface of the cell membrane. This G protein molecule, in turn, **(p. 210)** activates a molecule of an enzyme, cGMP phosphodiesterase, which breaks down many molecules of cGMP to 5′-GMP. When the intracellular cGMP concentration subsequently decreases, cGMP molecules are removed from cGMP-gated Na+ channels, leading to the closure of the channels. Closing of the channels blocks the influx of Na+ into the cell. In concert, vast numbers of photopigment molecules, G protein molecules, ion channels, and Na002B; ions go through this process leading to the hyperpolarization of the cell. This hyper— polarization propagates from the outer segment of the cone to the synaptic contact, where it reduces the rate of release of the neurotransmitter glutamate. This reduction in neurotransmitter release is the cone' signal that the cell has been illuminated.

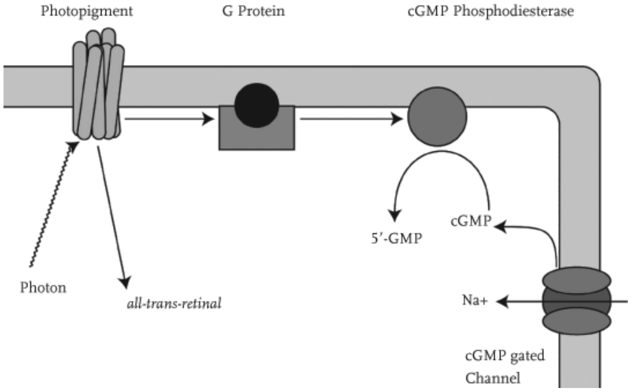

Fig. 10.4 The Phototransduction Biochemical Cascade.

10.3 The multiple realization of normal colour vision

Our central concern in this chapter is to explore the ways in which the discovery of differences in lower level realizers influences how scientists handle higher level properties. As a first philosophical concern, it is important to clarify what is at issue. The debate between the splitting versus the non-splitting strategy is not a debate about the descriptive powers of natural language. When the opponent of multiple realization observes that, faced with a possible case of multiple realization of a property G, one might recognize, say, two properties G_1 and G_2, and say that G_1 is uniquely realized by F_1, **(p. 211)** F_2,… F_n, and that G_2 is uniquely realized by $F^*_1, F^*_2, \ldots, F^*_m$, the claim is not merely one about what one or another natural language allows a scientist to express. It is uncontroversial to claim that in English we can speak of, say, being a green cone that is realized by cone opsin A and being a green cone that is realized by cone opsin B. Scientists can certainly use English to discriminate between properties that are realized in one way and properties that are realized in another. Such linguistic facts are no more interesting than the linguistic fact that scientists can speak of the property of being a green cone that realizes trichromatic vision and the property of being a green cone that realizes dichromatic vision. That is, the linguistic ability to individuate properties by reference to what realizes them is no more interesting than the ability to individuate properties by reference to what they realize. The matter of splitting versus not splitting properties is not one of linguistic usage. Instead, it is a question about the ontology scientists advance; it is about what properties scientists postulate in higher level theories in the face of discoveries at lower levels. Of course, the distinction between what is a linguistic matter and what is an ontological or theoretical matter is not perfectly clear, but such a distinction appears to be necessary if there is to be a substantive issue.

A second philosophical concern is clarity about what is meant by ‘normal colour vision’. In the literature being examined here, a person is said to have normal colour vision if that person makes normal colour discriminations. Such normalcy does not include other features of colour vision, such as rapidity of response, luminance sensitivity, etc. One could perhaps define a more robust, multidimensional concept of normalcy or perhaps find another conception of normalcy in other segments of the vision science literature, but such conceptions would not be the one in play in the research being reviewed here. We can tell that the concept of normalcy being invoked here depends only on how one makes colour discriminations, since this is the only type of test used to screen for normal colour vision. Thus, in reading through the description of methods, one might find that subjects were screened for normal colour vision using the Ishihara test. This very simple test involves 24 plates consisting of a circular field of dots of various sizes and colours. Normal trichromats easily recognize a numeral in the pattern of dots on each plate, where those having one or another colour deficiency will not recognize a numeral on one or more plates. Part of what makes this test so popular is how easily and quickly normalcy can be determined.[7]

(p. 212) 10.3.1 Normal colour vision and photopigment diversity

With philosophical preliminaries out of the way, we can now relate the science to the metaphysics of realization and multiple realization. At first glance, one might think that the theory of colour vision would strongly support the splitting of higher level properties. A number of studies have documented the existence of polymorphisms in the green and red photopigments.[8] For the red photopigment, it has been estimated that roughly 44% of the population has an amino acid chain, often designated Red (ala^{180}), that has an alanine at position 180, where about 56% of the population has an amino acid chain, often designated Red (ser^{180}), with a serine at position 180. For the green photopigment, it has been estimated that roughly 94% of the population has an amino acid chain, often designated Green (ala^{180}), that has an alanine at position 180, where about 6% of the population has an amino acid chain, often designated Green (ser^{180}), with a serine at position 180.[9] These different amino acid chains contribute slightly different absorption spectra, which are properties that they contribute to the realization of normal human colour vision. For example, Merbs & Nathans (1992) report that the wavelength of maximum absorption, λ_{max}, for Red (ala^{180}) is 552.4 nm and that the Red (ser^{180})λ_{max} = 556.7.[10] Thus, one might expect that the property of having normal colour vision would be subtyped.[11] The subtyping strategy proposes that vision scientists will postulate four types of colour vision corresponding to the four combinations of photopigments:

> Normal colour vision with Red (ala^{180}), Green (ala^{180}),
>
> Normal colour vision with Red (ala^{180}), Green (ser^{180}),
>
> Normal colour vision with Red (ser^{180}), Green (ala^{180}),
>
> Normal colour vision with Red (ser^{180}), Green (ser^{180}).[12]

Vision scientists could therefore describe an instance or instances of normal colour vision as being realized by one or another of these properties. However, **(p. 213)**

Table 10.1

Pigment	**Mean λ_{max}**	**SD**
Green	529.7	2.0
R2G3	529.5	2.6
R3G4 (Ala^{180})	529.0	1.0
R3G4 (Ser^{180})	533.3	1.0
R4G5 (Ala^{180})	531.6	1.8
R4G5 (Ser^{180})	536.0	1.4
Red (Ala^{180})	552.4	1.1
Red (Ser^{180})	556.7	2.1
G2R3 (Ala^{180})	549.6	0.9
G2R3 (Ser^{180})	553.0	1.4
G3R4	548.8	1.3
G4R5	544.8	1.8

the fact is that in these actual examples researchers have not abandoned the unitary property of having normal colour vision in favor of a set of four higher level properties.

The common red and green photopigment polymorphisms are only the tip of the diversity iceberg. There are, in fact, a relatively large number of distinct red and green photopigments whose absorption spectra have been determined by a variety of methods. Just to give a hint of this diversity, we report, in Table 10.1, data from Merbs and Nathans (1992).

Despite this well—known diversity in the red and green cone opsins and the well-known differences in their absorption spectra, vision scientists have not abandoned the category of normal colour vision. Nor have they introduced an elaborate and systematic taxonomy of dozens of subtypes of normal colour vision as suggested by the property splitting strategy.

Actual practice with regard to normal colour vision does not follow the property splitting strategy. Instead, vision scientists appear to accept, or at least tolerate, the existence of non-identical realizers of the higher level property of normal colour vision.[13] This is not to say, however, that scientists simply dismiss differences in lower level realizers as irrelevant to the higher level theory or properties. There is not *that* kind of autonomy of psychology. Scientists often study differences in lower level realizers as a means of explaining what they refer to as individual differences, differences from one human to the next. In vision science, a common approach to studying individual differences among normal colour perceivers begins by creating a pool of normal subjects **(p. 214)** by selecting only those who make correct classifications on all the Ishihara plates. Once the pool of normals is assembled, a more sensitive test, such as Rayleigh matching, is used to measure subjects' ability to make finer colour discriminations. In a Rayleigh match, subjects might be shown a target hemi- field of 589 nm light, then asked to adjust the amounts of 545 nm and 670 nm light displayed in a second test hemifield so as to have the two hemifields match.

He and Shevell (1994) report some results that are especially pertinent and illuminating. They develop a variant of the Rayleigh match test, a dual-Rayleigh match, which essentially involves subjects making one match using 545 nm and 670 nm light and another using 545 nm and 620 nm light. They argue that this dual match procedure enables them to locate the source of individual differences in the photopigments. Thus, the title of their paper is ‘Individual differences in cone photopigments of normal trichromats measured by dual rayleigh-type colour matches’. In other words, even among those individuals who have the property of having normal colour vision, there are variations in colour matches that arise from differences in photopigment absorption spectra. The introduction of He and Shevell's paper emphasizes the same point:

> The color matches of normal trichromatic observers show substantial and reliable individual differences. This implies the population of normal trichromats is not homogeneous, an observation that leads to the question of how one normal trichromat differs from another. In general, the physiological mechanisms that contribute to color-matching differences among normal observers may be classified as either pre-receptoral or receptoral. Pre-receptoral spectrally selective filtering can significantly affect color matches and therefore can cause individual differences. The influence of pre—receptoral filtering, however, can be eliminated with well-known techniques,… This implies that individual differences among normal trichromats are due in part to receptoral variation (He & Shevell, 1994, p. 367)

He and Shevell clearly recognize the impact of lower level realizers on higher level behaviour, but they do not deny the existence of normal colour vision and they do not subtype normal colour vision by means of receptoral differences. That is, they do not entertain the sorts of proposals one finds in the memory literature where, as an apparent result of discoveries about differences in real- izers, psychologists deny the existence of a unitary kind of memory in favour of subtypes of memory, such as long-term memory and short-term memory or procedural memory and declarative memory. We, thus, have cases that do not follow the eliminate—and—split strategy. Moreover, we see that an appeal to individual differences is a feature of actual scientific practice not recognized in our simple distinction between splitting and non—splitting strategies. Finally, we also appear to have some measure of autonomy of psychology from any putative dictates of lower level science.

(p. 215) 10.3.2 Normal colour vision and pre—receptoral properties

In the abstract to their paper, He and Shevell conclude with a comment that offers some comfort to the advocates of the property splitting strategy. They actually broach the possibility of subtyping normal colour perceivers on the basis of differences they find in the subjects' cone photopigments: ‘The ratio of two Rayleigh—type matches is a rapid and convenient measurement for assessing the L—cone [i.e. red cone] λ_{max} in the eye of an individual observer and therefore may be useful for classifying normal trichromats into phenotypic sub-types’ (He & Shevell, 1994, p. 367). So, scientists are at least willing to entertain the possibility of applying the property splitting strategy. The point to be made through our additional examples, however, is to indicate that the property splitting strategy is not likely to be invoked as uniformly and systematically as might be suggested by the simple formal schema with which this chapter began.

Return now to He and Shevell's distinction between the two sources of individual differences: pre—receptoral and receptoral. He and Shevell are willing to entertain the possibility of subtyping normal colour vision along the lines of differences in photopigments, that is, based on differences among certain realizers of normal colour vision. They do not, however, entertain the possibility of subtyping normal colour vision along the lines of differences in the pre—receptoral properties. They do not entertain the possibility of subtyping normal colour vision by means of combinations of differences in lens optical density and macular pigment optical density even when they explicitly note the effect these pre-receptoral features have on colour discriminations. Nor does such a taxonomy seem to appear in the vision science literature. As with differences in photopigment sensitivity, differences in the optical absorption properties of the lens and macula are treated as sources of individual variation among normal colour perceivers.

10.3.3 Normal colour vision and the phototransduction biochemical cascade

To this point, we have claimed that there are two kinds of counterexamples to the property splitting strategy in vision science. One is based on the properties of photoreceptors; the other is based on the properties of the lens and macula. The most interesting counterexamples, however, involve the properties of the elements in the biochemical cascade. Recall that, within a single cone, there are multitudes of molecules and ions of many types involved in the biochemical cascade that leads from photon capture to a change in neuro— transmitter release. There are the cone opsin molecules, the G proteins, the cGMP phosphodiesterase molecules, the cGMP molecules, the phospholipid molecules of the cell membrane, the sodium ions, the potassium ions, the ion channel components, and so forth. Each of these molecules and ions has one **(p. 216)** or more properties that it contributes to phototransduction, hence to normal colour vision. Of course, each of these molecules and ions will have properties that are irrelevant to normal colour vision, so that those properties will not be among the realizers. But, each molecule and ion will still have relevant properties spelled out in standard accounts of phototransduction.

Set aside the ions, the water, and cGMP and focus on the proteins in the biochemical cascade. Suppose that each of the proteins admits of mutations that only slightly alter the functionality of the protein in the cascade.[14] That is, just as there are variations in the amino acid sequences of the opsins, suppose that there variations in the amino acid sequences of the G proteins, the cGMP phosphodiesterases, and the monomeric components of the cGMP — gated Na^+ channels. If one reflects on the combinatorics of just these proteins, one finds that the number of types of normal human colour vision that one would have to postulate would increase dramatically. If we bear this in mind, we can see how impractical it would be to develop a theory of colour vision that hypothesizes a distinct type corresponding to each distinct set of lower level realizers. We do not have a comprehensive account of theoretical virtues in the higher sciences, since this is monumental task. None the less, it is plausible that one does not want a theory of human color discrimination abilities that tracks literally *all* the *bona fide* different realizers of normal colour vision given their vast numbers, since this would, to take just one example, mean that we can formulate few if any generalizations across subjects.

The problem here is not merely that the combinatorics of subtyping colour vision by way of its many lower level property instances is cumbersome. It is also that using *all* of the lower level realizer properties to individuate higher level properties leaves us without higher level theories that can track important regularities or generalizations at the higher level. Think of the properties of the G proteins, such as the rate at which they are activated by the retinal—free membrane—bound opsin or the rate at which they activate cGMP phosphodi— esterase. The many different values of these properties realize, in part, the colour processing properties of humans. Nevertheless, these properties, and their differences, are not the kinds of properties scientists want in their theory of human colour discriminations. Because these properties do not bring about changes in the color discriminations humans make, they are what we are calling 'orthogonal' realizers of colour discriminations.

(p. 217) To this point we have mentioned a number of times the idea that scientists do not treat all discoveries about differences in realizers equally. Now we are in a position to elaborate on this point by connecting our initial taxonomy of types of realizer to the cases we have examined. Some of the lower level properties that realize normal human colour vision are such that we discover small differences in their natures so that we are forced to posit 'parallel' variations in colour discrimination capacities. The latter are what we earlier termed 'parallel' realizers. And with such realizers discovering the differences amongst them entails our accepting variations in the colour discriminations persons can make. Differences in the light absorbing properties of the lens, macula, and photopigments are thus parallel realizers of colour discriminations. The lower level differences along the 'dimension' of light absorption lead to parallel higher level differences along the 'dimension' of colour discrimination.

It is these parallel realizers that have the most 'intuitive' appeal as a basis for adopting the subtyping and hence eliminate—and—split strategy, but, as we have seen, even in these cases this appeal is, at least at times, limited only to recognizing individual differences within a broader category. As a result, we can now see why a further distinction needs to be made amongst parallel realizers. Where differences amongst realizers leads only to scientists positing individual differences in the same higher level property, then we have what we termed ‘weak’ parallel realizers; when such discoveries lead scientists to posit two higher level properties, following the eliminate—and—split approach, then we have ‘strong’ parallel realizers.

As our last case highlighted, as well as these strong and weak parallel real—izers, there are also cases of orthogonal realizers. Discoveries of differences in these orthogonal realizers are such that differences in the properties they contribute to normal colour vision–differences in such things as the activation rates and reaction rates–do not make a difference to colour discriminations. Thus, they do not lead scientists to posit different higher level realized properties. Differences along the ‘reaction rate dimension’ are orthogonal to differences in the colour discrimination, so differences in orthogonal realizers do not provide even a *prima faci*e basis for invoking the property—elimination— and—subtyping strategy.

It is important to forestall some misguided objections to the parallel—orthogonal distinction among realizers. So let us emphasize, first, that both parallel and orthogonal realizers are in fact realizers. Both types of lower level realizers stand in the kind of non—causal, non—logical determination relation we take to be definitive of causal—mechanical realization. The point about orthogonal realizers is not that they have no higher level consequences. They have to have such consequences in order to be realizers at all. The point is, instead, that orthogonal realizers do not have higher level consequences of a particular sort, higher level consequences along a particular dimension **(p. 218)** relevant to the higher level property. Second, it is also important to note that being a parallel or orthogonal realizer is relative to both the higher level and lower level properties in question. Finally, one should not suppose that orthogonal realizers are not to be construed as realizations whose variations have relatively little impact on higher level properties. Instead, the idea is that the discovered variations in the orthogonal realizers lead to *no variation* in the higher level realized properties. In contrast, weak or strong parallel realizers are such that the discovered variations do lead to some variation in the higher realized properties.

10.4 Some broader philosophical context

Our chapter began with a succinct question about the nature of scientific theorizing. How do scientists accommodate findings about differences in lower level realizers in their higher level theories? We believe that the question, and our answer to it, should be of interest to philosophers of science who wish to understand the nature of scientific practice. That is one motivation for our project, but another stems from the fact that other philosophers have already touched on this question and given an answer that differs from our own. These philosophers have reasoned, in one way or another, that differences in lower level realizers will always lead to higher level differences that block multiple realization.[15] Rather than attempting to track all the argumentative paths that have been taken, we will select one that fits most closely with the framework we have established here, namely, Carl Craver's treatment of ‘dissociable realization’ (Craver, 2004). In fact a feature of Craver's analysis is that it also illustrates one of the general morals of our analysis–namely, that whether a higher level property is split or not, depends, at least in part, on the needs of good theory at the higher level.

Craver's project is to explain the reasoning underlying dissociation experiments in which brain lesions can impair one form of memory, such as declarative memory, while preserving another form of memory, such as procedural memory, thereby supporting the view that there is no such thing as memory *simpliciter*, but instead two distinct subtypes of memory, namely, declarative and procedural memory. At the heart of Craver's analysis is a principle of No Dissociable Realization NDR. What we want to show is that, upon clarification (NDR), becomes a principle that endorses the properties splitting strategy that we have argued is not uniformly adopted in science. Formulated in terms of properties, it is the following:

> **(p. 219)** (*NDR**) Instances of a property have one and only one realizer. If there are two distinct realizers for a putative instance of a property, then there are really two properties, one for each realizer. (Cf. Craver, 2004, p. 962).[16]

The first thing we need to do is to refine Craver's analysis to remove an ambiguity in the notion of ‘distinct realizers’. Consider two water molecules. Both of these molecules are polar, so both have oxygen and hydrogen atoms with properties that together realize the property of being polar. Here we should say that the properties of the water's constituent oxygen and hydrogen atoms provide what we might call *numerically distinct realizations* of the property of being polar. However, they do not provide what we might call *property distinct realizations* of the property of being polar. It is property distinct realizations that are implicitly taken to be involved in multiple realization. So, it is because a water molecule is polar in virtue of having two instances of hydrogen's electronegativity and one instance of oxygen's electronegativity (among other properties), where a hydrogen fluoride molecule is polar in virtue of having one instance of hydrogen's electronegativity and one instance of flourine's electronegativity (among other properties), that a water molecule and a hydrogen fluoride molecule give us multiple realiza— tion.[17]

So, how should we interpret the phrase ‘distinct realization’ in *NDR**? Let us consider the options. First, suppose we have a numerically distinct interpretation:

> (*NDR***) Instances of a property have one and only one numerically distinct realizer. If there are two numerically distinct realizers for a putative instance of a property, then there are really two properties, one for each numerically distinct realizer. (Cf. Craver, 2004, p. 962).

This, however, cannot be the correct principle. What it says, in essence, is that there cannot be a single property of being a kidney. If there are two numerically distinct realizers for the property of being a kidney, say, the left kidney and the right kidney, then there are really two properties–such as the property of being the left kidney and the property of being the right kidney–one for each numerically distinct realizer. Craver, however, rightly rejects this proposal (Craver, 2004, p. 967). Presumably, scientists do not introduce the **(p. 220)** subtypes of left kidney and right kidney, since this would tend to obscure scientific generalizations concerning kidneys. So, consider the property distinct interpretation:

> (*NDR****) Instances of a property have one and only one property realizer. If there are two property distinct realizers for a putative instance of a property, then there are really two properties, one for each property distinct realizer. (Cf. Craver, 2004, p. 962)

When framed in this manner, we can see that the principle looks to be a statement of the necessary property splitting strategy. However, we have now seen this approach faces problems. Among the oversimplifications inherent in this position is the tacit presupposition that, when we discover variations in realizers, the higher level theory has no role to play in deciding whether or not such differences at the lower level do, or do not, necessitate positing new properties at the higher level.

In fact, once we consider the role of higher level theory, we can return to our opening example of memory and explain how it does not, after all, lend support to our simplistic version of the property splitting strategy. Lesion studies by themselves do not distinguish between property distinct and numerically distinct realizations. Remove a bit of tissue X_1 from location

L_1 and a bit of tissue X_2 from location L_2 and let these distinct lesions have behavioural consequences. This alone does not tell scientists whether X_1 and X_2 have distinct neuroscientific or psychological properties. X_1 and X_2 might be the left and right instances of a common structure, such as the left and right eye, the left and right kidney, or perhaps the left and right halves of area V1. In such a case one might have merely numerically distinct, rather than property distinct realizations of a neuroscientific property.

Second, even if scientists were to have evidence that X_1 and X_2 are property distinct realizations, that would not tell them whether they are property distinct realizations of distinct higher level properties or property distinct realizations of the same higher level property. To put the matter in another way, given that declarative memory and procedural memory have property distinct realizations, it is not merely the distinctness of the lower level realizing properties that motivates them to split memory into declarative and procedural forms. Distinct sets of lower level properties can either give us two property distinct realizations of a single higher level kind (hence multiple realization) or two property distinct realizations of two higher level kinds (hence unique realizations). But, as we argued in the preceding sections, scientists facing a choice between these two options do not simply look to lower level realizers to make this decision. Instead, they look to principles of good higher level theory construction in making this choice. Higher, psychological level differences between procedural memory and declarative memory contribute to the splitting of properties; not mere differences in lower level realizers. **(p. 221)** Craver, in fact, implicitly recognizes this when he mentions a number of the psychological level differences. He writes,

> Declarative memories are triggered by the presentation of facts or the occurrence of events in the life of the person, and they play important roles in, for example, conversation, autobiography, or the simple act of reminiscing. Nondeclarative forms of memory (like procedural memory, iconic memory, priming, etc.) have their own unique triggering conditions (procedural memories are acquired by doing things, iconic memory by visual impressions, etc.) and play different roles in the life of the organism. These differences are reflected in the different kinds of stimuli used to produce and evoke memories of the different types (Craver, 2004, p. 966).

So, by our lights, the case of memory does not provide an illustration of the view that scientists subtype a higher level property when they find that it has distinct lower level realizers–thus taking the findings of the lower level on their own to determine decisions about which properties to posit at the higher level. Instead, we can now see that the case of memory supports our view that the decision whether to subtype properties at the higher level, or not, is driven, at least to some degree, by considerations of what makes for the better higher level theory and hence by higher level theory in *partnership* with the lower level accounts.

10.5 Conclusion

Neuroscientists and psychologists, at least at times, choose not to eliminate and subtype higher level properties when faced with the discovery of differences in lower level realizers. They have not postulated a myriad of distinct types of normal human colour vision each one of which corresponds to a distinct set of realizers. Neuroscientific and psychological theorizing does not hew to an extreme view according to which higher level taxonomy is always a slave to lower level taxonomy. But scientific practice also does not embrace the other polar extreme according to which neuroscience and psychology simply ignore differences in lower level realizers. We have shown that scientific theorizing does not necessarily adopt either extreme and we have described, at least in outline, how it actually proceeds in certain cases.

Sometimes scientists acknowledge the effects of lower level realizers by using them to explain individual differences at higher levels of analysis. To show this, we noted that biochemical differences in photopigments explain individual differences in subtle colour discrimination tasks, such as Rayleigh matching, even among individuals who are classified as colour normal by coarser tests, such as the Ishihara test. We also noted that differences in light absorption by the lens and macula are also used to explain individual differences among colour normals. The property of colour normalcy is, thus, retained by vision scientists, despite individual differences within that type. In **(p. 222)** other words, colour normalcy is retained in the face of the discovery even of parallel realizers and we have thus seen that we need to accept there are both weak, as well as strong, parallel realizers.

In addition to cases involving parallel realizers, we also saw there are cases where differences in realizers are acknowledged, but where this does not lead scientists to posit individual differences in a specific higher level property.[18] These are cases of orthogonal realizers. Our illustration of this approach was the apparent role of the properties of the components of the phototransduc— tion biochemical cascade in normal colour vision. This result will be surprising to the philosophers who have reasoned that the discovery of distinct sets of realizers should always lead to the subtyping of higher level properties, hence that all distinct sets of realizers constitute strong parallel realizers. With orthogonal realizers, differences in realizers result in no difference at the higher level relevant to the higher level properties under discussion. Thus differences in the properties of the components of the phototransduction biochemical cascade do not lead to differences in colour discriminations. In orthogonal realizers, one has discoveries about differences in lower level realizer properties that scientists find no interest in incorporating into their higher level theories.

What do the foregoing observations about a segment of vision science, if we assume them to be descriptively accurate, tell us about neuroscience and psychology? Why do neuroscientists and vision scientists reason as they do? As we have seen, the short answer is that there is some measure of autonomy of psychology even in the age of neuroscience. Lower level sciences can have closer or more distant relations to higher level sciences, as revealed by parallel and orthogonal realizers, but exactly how lower level science influences higher level science is determined, at least in part, by the needs of higher level science. Higher level science is not a mere repository of lower level differences, but a body of theoretical knowledge in its own right and thus a partner with lower level science in our ongoing project of investigating the world around us.

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Notes:

(1) A third possible scientific strategy would be to keep G and add subtypes G_1 and G_2. This strategy would leave G to be multiply realized, which would make it useless for blocking multiple realization.

(2) We thus endorse a weakened version of the theory defended by Shoemaker (1980) under which in the actual world all instances of a property contribute the same powers under the same conditions.

(3) The dimensioned view is introduced and defended by Gillett (2002, 2003). It is combined with a theory of multiple realization and applied to various neuroscientific and psychological examples in Aizawa and Gillett (2009a, 2009b, Unpublished). Those who reject our theories of realization and multiple realization might read what follows more restrictively as simply articulating what we take to be some of the implications of this combination of views.

(4) It is sometimes held against the dimensioned view that it appeals to property instances, rather than simply properties, and that it is overly technical on this score. In the example of polarity, however, we can see quite clearly how one really needs to appeal to the number of instances of the property of having an electronegativity of 2.2–rather than merely to the property of having an electronegativity of 2.2–in order to explain the realization of the polarity of a water molecule.

(5) Note that we focus throughout on the multiple realization of properties through the differential realization of their instances. However, we should note that a single instance in a certain individual may also be multiply realized over time. Having noted this possibility we leave it to one side in order to focus on the more usual case of the multiple realization of properties.

(6) The terminology for describing these cones is not consistent across the disciplines that study them. In psychology and psychophysics, one is more likely to find the cones described as L-cones, M-cones, and S-cones or long-wavelength-sensitive (LWS), medium-wavelength-sensitive (MWS), and short-wavelength-sensitive (SWS), where biochemical studies of the opsins often use red, green, and blue. Nothing, as far as we can tell, depends on our choice of terminology.

(7) One can be worried about what sort of normativity there might be in the concept of ‘normal colour vision’, but much of this worry might be avoided by simply changing the higher level property that is invoked. So, for example, all of the arguments that are developed here would go through essentially unchanged even if we invoked other higher level properties, such as being an anomalous trichromat, being a dichromat, being a deuteranope, being a protanope, or being a tritanope. The property of having normal colour vision is more useful than these others for two reasons. First, the property of having normal colour vision is easily described operationally as in the body of the text above. Second, the literature on this property is more extensive than that on the other properties.

(8) See (Neitz & Neitz, 1998; Sjoberg, 1998; Winderickx *et al*. 1992).

(9) This composite data is assembled in Sharpe, Stockman, Jägle, & Nathans (1999).

(10) Using different techniques, Sharpe *et al*. (1998) report that Red (ala^{180})λ_{max} = 557.9 and that the Red (ser^{180})λ_{max} = 560.3, where with still different techniques, Asenjo, Rim, & Oprian (1994) report that Red (ala^{180})λ_{max} = 557.9 and that the Red (ser^{180})$=_{max}$ = 560.3.

(11) In fact, in a paper to be discussed below, the authors actually appear to broach the possibility of subtyping normal colour perceivers on the basis of differences they find in the subjects' cone photopigments: ‘The ratio of two Rayleigh-type matches is a rapid and convenient measurement for assessing the L—cone λ_{max} in the eye of an individual observer and therefore may be useful for classifying normal trichromats into phenotypic sub—types’ (He & Shevell, 1994, p. 367). We shall return to this claim later.

(12) The subtyping strategy does not specify how the higher level psychological properties will be named or described; it only asserts that there will be some form of subtyping. Here we subtype the properties by reference to the molecules involved.

(13) To repeat a point made in an earlier footnote, there is nothing special in this regard concerning normal human colour vision. The argument applies just as well to the property of being a tritanope. It applies only slightly less well to being a protanope or being a deuteranope, since by definition these deficiencies mean a lack of red or green cones.

(14) Here it would be convenient to be able to cite some studies that document the variability in the proteins, but such studies are hard to come by, if they even exist yet. Thus, rather than direct measurements of variability in the G proteins, the cGMP phosphodiesterases, etc., one must settle for considerations of the general nature of proteins. These are likely to be variable due to the supposed underlying genetic variability, which is essential for evolution by natural selection. The lack of direct evidence might, thus, be taken to make this illustration more speculative than the preceding two.

(15) Here we have in mind Shagrir (1998); Craver (2004); Couch (2005); Shapiro (2008), and Polger (2008).

(16) In a late section of his paper, Craver proposes that arguments involving dissociable realization only work for properties and activities. This is why we skip over the NDR formulation in terms of natural kinds directly to *NDR** formulated in terms of properties. This does not distort Craver's views.

(17) Some might prefer to mark the distinction we have in mind here by saying that two individual water molecules provide two tokens of the same type of realization of polarity, where a water molecule and a hydrogen fluoride molecule provide two tokens of two distinct types of realization of polarity.

(18) Another sort of case we have not discussed here is when one gets multiple realization of a higher level property G by having the differences between F_1, F_2, … F_n, and

$$F^*_1, F^*_2, \ldots, F^*_m$$

'cancel each other out'. To take a suggestive example, one might get multiple realization of a given stroke volume of an automobile engine's cylinder by distinct combinations of stroke length and cylinder area.