Colour: An Exosomatic Organ?

Jaap van Brakel¹ and Barbara Saunders²

ABSTRACT

According to the dominant view in cognitive science, in particular in its more popularised versions, colour sensings or perceptions are located in a 'quality space'. This space has three dimensions: hue (the chromatic aspect of colour), saturation (the 'intensity' of hue), and brightness. This space is structured further via a small number of primitive hues or landmark colours, usually four (red, yellow, green, blue) or six (if white and black are included). It has also been suggested that there are eleven semantic universals - the six colours previously mentioned plus orange, pink, brown, purple, and grey. Scientific evidence for these widely accepted theories is at best minimal, based on sloppy methodology and at worst non-existent. Against the standard view, it is argued that colour might better be regarded as the outcome of a social-historical developmental trajectory in which there is mutual shaping of philosophical presuppositions, scientific theories, experimental practices, technological tools, industrial products, rhetorical frameworks, and their intercalated and recursive interactions with the practices of daily life. That is: colour, the domain of colour, is the outcome of interactive processes of scientific, instrumental, industrial, and everyday lifeworlds. That is: colour might better be called an exosomatic organ, a second nature.

colour appearance, colour spaces, dimensionality of colour, unique hues, basic colour terms, standard observer

Sec. 1 THE THREE-DIMENSIONALITY OF COLOUR

Sec. 1.1 Borrowing from physics

One principal conceptual tool that underlies discussions of colour, is the phenomenological colour space. As used in colour science this space is partly distinct, yet partly derivative from, the physical colorimetric spaces used to predict what colour a mixture of wavelengths of light will appear to have for the 'standard-observer' (see section 1.2). Our concern is not with the capacity to discriminate lights of different wavelength - a capacity humans share, for example, with chimpanzees, pigeons, goldfish, bees and jumping spiders. Our subject is the psychological or phenomenological colour space (also called 'appearance colour space').

The prevailing doctrine stipulates that colour experience is realised in a (closed) space defined by three dimensions: hue, brightness, and saturation. If thought to be a cylinder, then the pure chromatic colours (or hues) can be found along the circumference (red, orange, yellow, chartreuse, green, turquoise, blue, purple and all intermediate shades). The vertical dimension (the axis of the cylinder) runs from dark (or black) to bright (or white) and the radial dimension gives the saturation of the colour (from a central achromatic grey to the most saturated colours on the circumference). The distinction between light and dark blue is a difference in brightness or light/dark, as is the difference between yellow and brown; on the other hand, each of yellow, brown, light blue and dark blue can be more or less saturated. Some colours only occur at certain levels of brightness (for example yellow and brown); others only at certain levels of saturation. Beige, for example, is always of low saturation; if saturation is increased, 'it' becomes yellow, pink or orange. For the sake of simplicity a cylinder has been chosen to explain the structure of the colour space. Many other geometrical forms have been proposed, both regular and irregular, the dimensions of which may be defined differently (see section 1.3). But on the standard view, it is always assumed that the psychological-phenomenal colour space has three dimensions.

¹ Department of Philosophy, K.U. Leuven; e-mail: Jaap.vanBrakel@hiw.kuleuven.ac.be.

² Clare Hall, Cambridge University; e-mail: bacs2@cam.ac.uk

How did colour become three-dimensional? For the past one hundred and fifty years it has been a ‘scientific fact’ that colour has three dimensions. The forceful establishment of the fact of colour’s three dimensionality was brought about by Maxwell, Grassmann and von Helmholtz in the 1850s and 1860s. Maxwell wrote:

We do not require any elaborate experiments to prove that the quality of colour can vary in three and only in three independent ways.

The trivariance of colour was specified by Maxwell in two alternative (and for him interchangeable) ways: as tint (hue), purity, and shade (lightness), and as three primaries (‘for instance, redness, blueness, and greenness’). It was obvious to him that ‘[t]o bring a quality (such as colour) within the grasp of exact science we must conceive it as depending on the values of one or more variable quantities’. Maxwell’s proposals and similar ones of Grassmann and von Helmholtz, formed the basis of psychophysical definitions of light and colour in terms of three dimensions. Colour was defined as a specific and replicable response to a physical phenomenon - an invariant sensation common to all observers.

Hering has shown that from Newton onwards, the geometrical ordering of the relations between the physical properties of light had been projected onto an alleged geometrical ordering of colour experiences (*Empfindungen*). This identification was made explicit, and extended to all mixtures of light by Grassmann and endorsed by von Helmholtz and von Kries. Grassmann provided ‘complete’ physical rules for mixing coloured lights. This included a theory of metamers predicting (approximately) which wavelength spectra will ‘match’ (i.e. will be reported as being the ‘same colour’ by the ‘standard observer’).

Hering gives quotations from Grassmann, von Helmholtz, and von Kries, showing that they stated explicitly that (psychological) hue corresponds to (dominant) wavelength, that whiteness (or saturation) corresponds to the proportion of a homogeneous spectral light mixed with light-that-appears-white, and that psychological brightness (*Helligkeit*) corresponds to the intensity (or quantity) of (physical) light. Hering shows convincingly and in great detail, that these assumptions of isomorphy (see section 3.1) are neither supported by empirical data, nor by ‘a priori’ arguments. Hering’s arguments however had little impact.

Although specialist publications in colour science usually make a clear distinction between ‘colour’ and ‘wavelength’, folk wisdom that colour is nothing but wavelength is encouraged by such influential scientists as Dawkins, who says: ‘The colours that we actually experience, the subjective sensations of redness and blueness, are arbitrary labels that our brains tie to light of different wavelengths’.

By the 1940s reference to ‘the ideal psychological colour solid’ was taken to be self-evident. The idea was compelling both in colour science and psychology; later it was reimported into philosophy via cognitive science. The idea of a three-dimensional phenomenal colour space, with dimensions of hue, brightness, and saturation, has consequently been presupposed in all theoretical and philosophical discussions.

Sec. 1.2 Colorimetry and the standard observer

In the first half of the twentieth century the combination of standards and instrumentation promoted the view of colour as essentially a physical phenomenon and that the CIE-definition of the Standard Observer in the 1930s mediated the acceptance of physical instruments as alternatives to the eye. However, even though the physicist’s CIE-definition has dominated colour science, ‘eyes’ have not disappeared from colour science - on the contrary. Since the demise of behaviourism and the rise of the various cognitive sciences, experiments with eyes (alive or dead; human or nonhuman) have increased enormously. But those eyes are invariably ‘well-regimented’. Typically in experiments with spectral lights, eyes are put in a ‘neutral equilibrium state of adaptation’, which means that they ‘see the test fields after remaining in the dark for ten minutes’. With surface colours, experimental conditions too are strictly standardised. In addition experiments have increasingly been carried out to record responses to standardised stimuli by various cells in the retina and ‘higher-up’ in the ‘visual pathway’. In early experiments, monkeys were anaesthetised; advanced technology however now permits drilling holes in their skull and/or the severance of connections in their brain to allow single cell recordings of stimuli responses in a wakeful state.

In 1932/33 a committee of the Optical Society of America (OSA) almost split over the addition of ‘extra’ attributes to characterise a perception-based psychological colour concept. Nonetheless consensus was eventually reached on three attributes: hue, saturation, and brightness (or lightness). Disagreements between different types of experts (primarily physicists and psychologists) could be avoided by agreeing on the results of experiments in artificially restricted conditions, thus portraying colour as a meaningful and replicable entity.

Physically, everything to do with the properties of light and mixtures of different lights is well-defined (in CIE terms), but it is doubtful if the term ‘space’ is appropriate when talking about a phenomenal colour space. Using the term ‘space’ in relation to colour is inappropriate unless defined in purely physical terms. The latter can be used as a psychophysical *model* for human responses to coloured lights in restricted circumstances. But to transfer that notion from the physical to the phenomenal is illegitimate.

It should be stressed that the 1931 or 1964 CIE Standard Colorimetric Observer is *defined* as the observer for whom two colours will look alike when they have the same CIE tristimulus values (and possibly widely differing wavelength spectra) *provided they are seen under the same photopic viewing conditions*. For colours in general, the tristimulus values differ over a wide range. Under ‘normal conditions’ an observer looks at situations (seeing the illumination as separate from the objects being illuminated), not at stimuli as such. The standard observer, as defined, merely ‘acts’ as an automaton, its linguistic metric accurately representing the metric of the colour space.

The background to the prevailing colorimetric approach is of course the general stimulus-response approach to perception, which assumes that the response to a given configuration is unique. As the well-known Kodak colour scientist Evans once put it:

We unconsciously adopt from physics and mechanics the *unitary* nature of the outcome of a known system of causes. In doing this we err, not in the belief of cause and effect, which there is no need to question, nor in the belief that there can only be a single outcome, given sufficient knowledge. The error comes in the belief that what is seen must be a single entity.

Sec. 1.3 Proliferation of colour spaces

Throughout the twentieth century a variety of colour spaces have been proposed. It is generally assumed that all are about ‘the same thing’ (in line with the isomorphy thesis [see section 3.1]). The large number of different colour spaces has not undermined the belief in one Ur-space; variety is either written off as due to practical interests or as ‘representing’ colour at different ‘levels’. There is the Munsell solid, the Swedish Natural Colour System (NCS), the German DIN based going back to the system of Ostwald. There’s Land’s retinex space. The OSA system, the ‘most advanced’ colour space today, comes closest to modelling an isotropic space (same distance = same number of jnds).

Although its aim was to construct a colour similarity space, thirty years after the OSA-project began, the committee, consisting of the most renowned colour scientists in the USA, concluded that:

No regular rhombohedral lattice sampling of colour space can exist; we will produce the best approximation to such a lattice that we can design.

If this is true, then no empirical colour similarity space exists. Moreover the best approximation, were it to exist, would not be based on hue, saturation and brightness. OSA space has a lightness axis, and a *j*- and a *g*-axis. The latter two, though chromatic axes, cover all lightness levels. It is best to think of *j* and *g* simply as abstract symbols unassociated with colour names.

Given this proliferation of colour spaces, each with its own practical advantages and disadvantages, why continue to talk about *the* colour space and its purported three dimensionality? Why are the differences between Munsell, NCS, retinex, and OSA not regarded as different (incompatible) paradigms? Different colour systems claiming to be equally spaced show very differently spaced hue circles. To be sure there is a pragmatic reason for psychological or phenomenal colour to have three dimensions, no matter how specified: it is easily mapped into physical the CIE space.

If one leaves the domain of trichromatic vision, i.e. the putative three types of cones in the retina, the variety of colour spaces potentially proliferates in a more fundamental way. Any organism that responds differentially to wavelengths has been ascribed its own unique species-specific colour space. In addition to dichromats and trichromats, tetrachromats and pentachromats have been proposed. But what could this mean? Consider a feather-sorting contest for pigeons who allegedly live in a four- or five-dimensional 'colour' world. The pigeons can be trained to divide a pile of white feathers into two (or more) piles - feathers which all look the same white to humans. How can that be? Physically we can establish that some feathers but not others, reflect UV-light, which the pigeon is apparently able 'to see' (i.e. its discriminatory capacities include being sensitive to the presence of UV-light - a capacity humans don't have). What would it add to this to say that the pigeon sees extra hues and has a 'colour' space that is incommensurable with that of humans? How do we know that the non-UV white looks *white* to the pigeon? Why would the sensitivity to UV-light show up phenomenally (assuming that term makes sense for pigeons) as an extra unique hue? Why not as an extra type of brightness, or as a metallic look, or as if vibrating slowly? We could try to design experiments to exclude such possibilities, but what could such experiments show over and above the pigeon's sensitivity to UV-light?

Sec. 1.4 Evidence for three dimensionality

It has been suggested that MDS gives evidence for the three-dimensionality of phenomenal colour, but it does *not*. Multidimensional scaling depends heavily on the stimulus sample chosen, requires an exhaustive series of similarity judgements and even then sometimes fails numerically. Adding a dimension will usually improve the overall fit of the model, but soon the improvements become insignificant [i.e. MDS is just a statistical data fitting instrument]. Why then is it assumed that colour - in some fundamental ontology - is three dimensional? This might be expected to be a philosophical or foundational question. Yet few scientists have raised the issue. Moreover, a cursory look at the colour science literature of the past century shows a variety of other possible features of colour appearances.

From the late nineteenth century onwards, there have been dissenting voices about the three dimensions, although with little impact. At best one might find the recognition that surface colour is three dimensional only *when seen in aperture mode* - where it should be stressed that aperture mode is an 'invented' way of seeing. Grassmann's colour matching laws have been universally quoted as the basis of the empirical proof of three-dimensionality, though these laws have long been known to apply only to 'the ideal representative observer'. There is a host of other problems, both 'phenomenal' and 'psychophysical', that make the notion of three dimensionality into the abstraction of a non-existing entity; for example:

- Hue is an imperfectly known function of purity when luminance and dominant wavelength are constant.
- Colours of opposite hue are not recognised as 'equivalent' when they are of the same luminance reflectance and saturation degree.
- There is no consensus on the relation between luminance, brightness, lightness and/or whiteness; that the relation between brightness and intensity is a psychophysical law, is disputed (brightness judgements are subject to successive, simultaneous and other contextual variables). The relation 'brighter than' is not transitive. Even for brightness, contrast is usually a more important variable than luminance.
- Lightness is a comparative parameter, not an attribute of a singular colour. Strongly chromatic colours may appear lighter than others, even if they are of the same saturation, whiteness, and blackness.
- Problems arise with the psychological difference between black/white, dark/light, and dull/bright; natural zero for brightness is not black or absolute darkness, but brain grey.
- Purity (the physical correlate of psychological saturation) fails to dovetail with saturation in any clear way; the notion of saturation breaks down when applied to lights in the case of negative contrast.
- Because two colours may appear unequal in clearness, even if equally light, lightness and whiteness (blackness) are separate concepts - also called the bi-dimensionality of grey colours.
- Hue, brightness and saturation are interdependent; perceiving hue, lightness and saturation requires elaborate training to separate their interactions.
- The difference between the appearances of aperture and surface colours is so great that making colour matches between them is virtually impossible.

- None of the existing systems of colour classification achieves the goal of uniform perceptual intervals between any two adjacent colours; it is impossible to represent colour in Euclidean space.
- Many man-made pigments (e.g. those in enamel paints) have reflectance functions that cannot be represented uniquely by the visual system. Similar problems arise when the illuminant contains chromatic frequencies higher than 5 to 10 c/μm.
- The spatial context in which a light is viewed, strongly affects its mode of appearance. Spatial and temporal separation of samples to be compared cause long-recognised difficulties. Attributive abstraction (which is asked in an experiment) is peculiarly difficult in cases of strong association. There are difficulties involved in the difference between looking for the specific differences asked for and ‘any’ difference (whatsoever). Complex features arise because of the complex spatial and temporal patterning of the light stimulus (or more generally the patterning of the energy field triggering the observers’ transducers). There is a qualitative difference in colour appearance between fovea and peripheral retina vision.
- There are significant differences in the dimensional relations for ‘trained’ and ‘untrained’ observers. Untrained subjects tend to respond to the holistic overall similarity relations of stimuli and are not sensitive to underlying dimensions.
- Colour matching (Grassmann additivity) is not as simple as was imagined, either in a symmetric or in an asymmetric context. In a colour-matching experiment, the focal element of one stimulus is compared with the focal element of another. However, only the focal elements are judged to match, and they are required only to match in *colour*, i.e., in hue, saturation, and brightness, not necessarily in other perceptual attributes such as size, duration, and glossiness.
- The light that is seen to be illuminating objects is perceived as separate from the objects. For the colour appearances under chromatic illumination, there seem to be two colours ‘one behind the other’. The ‘problem of colour constancy’ may well be artificial in that it follows from the (unjustified) dual conception of ‘object colour’ and ‘illumination colour’.
- The problem of how perceptual concepts such as ‘surface’, ‘object’, and ‘light’ are ‘constructed’ is never addressed.

Sec. 1.5 Conclusion

There seems little doubt that the attributes hue, saturation, and brightness are no natural classification. Rather they were derived by von Helmholtz and von Kries from the physical operations for measuring wavelength, light intensity and dilution of a stimulus with white light, which they promoted against opposition. They acknowledged that the choice of these dimensions was ‘arbitrary’, but nevertheless accepted them because of the rigour of the ‘corresponding’ physical concepts.

Sec. 2 FURTHER STRUCTURING OF THE COLOUR SPACE

Sect. 2.1. The developmental trajectory of colour circles and spaces

Perhaps the 1611 colour circle of Forsius is the first to use the notion of ‘opponent colours’ in the circle (placing white *opposite* black). It had sixteen equally spaced partitions, including red (opposite blue), orange (opposite pale green), and violet-brown (opposite chalk grey). Forsius also presented a crude drawing of a colour sphere. During the eighteenth century colour circles became hue circles. The most famous is Newton’s of 1704, composed of seven unequally spaced hues and following in every detail Descartes’ 1618 circular spacing of seven musical tones. The sequence of hues followed the spectrum Newton had observed in his prism experiments. He also introduced the idea that the degree of purity of any colour is expressed as the distance from the middle point of the circle. This made colour explicitly a two-dimensional spatialisation.

A whole gamut of colour circles was proposed in the following two centuries, often motivated by the practical needs of painters. In 1708 Boutet had already redrawn Newton’s colour circle with seven *equal* parts, replacing Newton’s two blues (blue and indigo) by two reds (fire-red and crimson). Ordering the colours first on a linear scale between white and black (or lightness and darkness), spacialising it into a colour circle, and removing the achromatic colours, was a precondition of the *mathesis*, measurement and standardisation of colour.

Goethe's colour circle has six equally spaced 'opponent' colours: red, orange, yellow, green, blue, purple. It was imported into Runge's *Farbenkugel* of 1810, with white above and black below, which added a dimension perpendicular to the plane of the colour circle. Although there were precursors, this was the first influential three dimensional representation of colour.

In contrast to the three primaries red, blue, and yellow favoured by Maxwell and von Helmholtz, Hering suggested that: 'language has long since singled out red, yellow, green, and blue as the principal colours'. In 1902 Ebbinghaus followed Hering's suggestion of four unique hues, redrew Runge's *Farbenkugel* in the form of two pyramids, with a square base of red, green, blue, and yellow. This is essentially the colour space in use today. Though a colour circle with the opponent hues red/green and yellow/blue at right angles is the 'official' version, Goethe's circle is also widely used. All technological products - printing, photography, TV and computer monitors - use three primaries.

As already remarked, Grassmann, Maxwell, and von Helmholtz developed the suggestions of Newton and Young for physical 'colorimetric' rules for mixing light of different wavelengths; the implication of these rules was that 'white' or the 'white - black axis' was to be placed in the centre of the colour circle, with 'purity of light' increasing from the centre to the circumference. Furthermore von Helmholtz showed that, contrary to the Newtonian assumption, 'true' purples were not found in the spectrum at all. Hence 'rolling up' the spectrum does not produce a colour circle; a stretch of purples must be added. von Helmholtz put the purples on a straight line to link the curve representing the spectral colours. He also showed white is not equidistant from each hue; therefore he put white in the barycentric centre so that colorimetric mixing rules could be obeyed. Colorimetrically speaking therefore a colour *circle* makes little sense.

To summarise, the material realisation of the colour space was developed from a linear scale of colours running from white to black; this was transposed into a circle of chromatic 'pure' hues, and subsequently re-modelled on the solar spectrum. However purples had to be added to make the circle 'complete'. Placing white in the (barycentric) centre introduced the dimension of purity or saturation; adding a white - black or light - dark axis through the centre, introduced the third dimension (brightness). Depending on the preference for three, four, five, six, or seven 'primary' colours, the three dimensional colour 'solid' could take on different configurations (sphere, cylinder, cones, irregular solid, ...).

Sect. 2.2 Further structuring of the colour space: unique hues and opponent colours

The most common assumption of the further structuring of the colour space is that of four unique hues, which is derived from Hering's opponent process theory and which replaced the Young-Helmholtz 'three primaries' model. Being 'phenomenological', Hering's approach had a marginalised existence during the epistémé of behaviorism. Whatever justification is given for the four unique hues, it *precedes* psychophysical and neurophysiological research, as most text books will tell you explicitly.

Of the twenty commentators on Saunders and van Brakel (1997), seven explicitly objected to the questioning of four unique hues. Most invoked 'experience' in the sense of 'introspectively obvious' as the bottom line. However, the unique points cover the virtually the whole spectrum. In addition, unique red, not being in the spectrum, raises questions about the 'operational' meaning of 'unique hue'. Moreover, since Hering, uncertainty abounds about whether brown is 'unique' or not. Metallic colours too have been described as a 'group of colours we perceive as *unique*', which raises questions about the concept of colour being unique. It is true that if one averages data, the unique hues become more constant - that after all is what averaging does. But the issue is not whether English speakers roughly agree on what, for example, is unique green, or whether brown, is or is not, unique. More important is the issue of whether asking people to point out the unique hues reveals anything more than their command of English colour terms (defined by the average speaker), and compliance with the experimenter.

Since Newton proposed his seven colours, it has been debated whether the spectrum can 'naturally' be partitioned in a small number of hues. It has been claimed four-month-old infants as well as monkeys and honeybees divide the spectrum into four categories (red, yellow, green, blue): 'to see colour is to categorize the spectrum into hues'. However, it has been pointed out that 'the colour appreciation of lights ... is highly dependent upon a great number of parameters. And it has been suggested that testing with methods such as habituation and preferential looking (social practices of the laboratory) may itself lead to a *re-constitution* of visual experience, as experimenters hold as constant as possible all variables other than

wavelength. Helmholtz already commented: 'there are no real boundaries between the colours of the spectrum. These divisions are more or less capricious and largely the result of a mere love of calling things by name.' And this would seem to be the most 'objective' conclusion.

In support of the opponent process theory it is common in the philosophical literature to quote the cancellation experiments of Hurvich and Jameson. However, it is noteworthy that the original theory was 'curvitted' with data for only two observers. In more recent publications always the data for only one observer are represented (those for 'J' which look neater).

Numerous sources state that the impossibility of a colour being both red and green supports the view that there are two pairs of opponent unique hues. However, the statement 'a colour can be both red and green' is not a meaningful statement (in contemporary English); hence it cannot support (or falsify) anything.

Many writers still refer to the notorious De Valois data of the 1960s, though as Boynton recalled recently:

DeValois et al. use of the names red, yellow, green, and blue to classify groups of data was entirely arbitrary and ignored a virtual continuum of opponent responses that exists as a function of crossover wavelength in the data of individual units.

Dissenting voices have increased in the last few decades, though as yet without much effect. We are reminded that in 1907 a student of Hering (Tschermak) reported that to obtain a white light by adding green to unique red, one doesn't need a pure green but a somewhat bluish-green. Many studies subsequently confirmed that mixing unique red and unique green yields a light of yellowish appearance; unique blue plus unique yellow appears reddish; desaturating a spectral unique blue makes it appear reddish. Although these empirical results are known by colour-vision experts (and not disputed), it is still often implied in text books and top journals that the zero-output cross-over points in chromatic response functions correspond to unique hues that additively combine to yield *neutral* sensations.

There is talk of a third level in the visual system, tuned to many directions around the colour circle that derive their inputs from the second stage mechanisms. It is pointed out that one finds a wide range of variation in the strength of the red and green sensitive cones, contributing to a colour-opponent cell. Neutral points can be found almost in any part of the visible spectrum (between 420 and 650 nm). And many well-known colour scientists have started to worry what they have been up to in the latter decades of the twentieth century. For example Mollon wrote in 1995:

Contrary to what one might read in text books, there is no physiological evidence in the visual system for cells that secrete the sensations of yellowness and blueness or redness and greenness. ... At the cortical level, there are neural channels tuned for many different directions in colour space. ... The special phenomenal status of the four pure hues is perhaps the chief unsolved mystery of colour science.

And very recently, de Weert (in Saunders and van Brakel 2002) said:

It may seem hard now to believe, but at the end of the sixties it was really believed (and written) that the whole colour vision process had essentially been solved, and that colour coding was more or less complete at the level of the retinal ganglion cells already.

We conclude with a 'simple' illustration of the utter simplicity sometimes displayed in this literature. The received story about the colour circle has red/green and yellow/blue at opposite poles of orthogonal diameters. This seems plausible. But why? The colour circle in Newton's *Opticks* doesn't confirm these insights. Hardin, referring to a proximity analysis of qualitative similarity judgements of colours says: 'Notice particularly that the unique hues ... are spaced about 90 degrees apart'. However, the picture he presents would fit the painter's colour wheel better (with the primaries yellow, blue and red placed 120 degrees apart), or, alternatively, the colour hexagon used by printers, six primaries (magenta-red, violet-blue, cyan-blue, green, yellow, and orange-red) are 'naturally' placed 60 degrees apart - a variant of Goethe's circle. Furthermore, the data equally fit the five Munsell primaries, red, purple, blue, green, and yellow, about 72 degrees apart. The OSA system also supports dividing the colour perimeter into roughly *five* equal sections. Whether the colour circle is partitioned into three, four, five, or six 'equal' parts, it looks equally 'natural'. This draws attention to a certain arbitrariness and inconsistency in the colour discourse, which draws on experimental evidence in a way that would give a hard-line positivist a migraine. There is a tradition going back to the seventeenth century of presenting red and green, and yellow and blue as opposites in the colour circle. But one cannot determine by direct perceptual comparisons whether green, blue-green, or blue is

‘opposite’ or ‘complementary’ to red. It is more appropriate to say that talking about red, yellow, green, blue the way we do, is part of our grammar of colour words. Moreover, in all these discussions of the number of primary *colours* it is still assumed that the colour domain is universal and autonomous.

Sect. 2.3. cross-cultural significance of red, yellow, green, and blue

Long lists of phenomenal facts that can be ‘explained’ by the opponent-process theory are often presented in its support. For example, to explain that green is a unique hue it is claimed that each observation of green causes in ‘normal’ human beings a negative signal in the LM channel and no signal in the LM/S channel, the absolute value of which is larger than the signal in the LM channel. It doesn’t matter whether one knows what ‘LM channel’ means. It is enough to be impressed by what looks like a straightforward simple definition. The rhetoric suggests that the fact that ‘green’ turns up in psychophysics with such a ‘simple’ definition supports that it *is* simple, i.e. a unique hue. But this is an inference to the most lovely explanation of the worst sort. Assume you would favour *lhenxa* as a unique hue, the reference of which in standardised, ‘decontextualised’ experiments includes most greens and yellows; both a yellow lemon and a green apple would be *lhenxa*. Why isn’t *lhenxa* (and not green) a unique hue. After all, according to the opponent process theory seeing *lhenxa* causes in ‘normal’ human beings a negative signal in the LM channel and a positive signal in the LM/S channel. One might even claim that *lhenxa* ‘scores’ better, because it has an even ‘simpler’ explanation in terms of the opponent processes theory. I’m not making up the example of *lhenxa*; it is a word of the language Kwakw’ala, still spoken on part of Vancouver island.

That a green apple and a yellow lemon share the *same* colour, viz. *lhenxa*, is as easy to learn as it is to learn yellow and green. Note that the problem cannot be rationalised away by reverting to the idea of ‘primitive’ languages which don’t have abstract concepts. Halkomelem speakers may use words which, in a decontextualised hue context, might be glossed as white, black, red, blue, purple, brown, orange, and pink, but *all* speakers use the same word for both yellow and green. How is it possible that Halkomelem and Kwakw’ala and many other speakers around the world overlook the perceptual salience of unique yellow and green?

Is there any risk of bias in appealing to experience or the colour grammar of modern English? We think there is, in particular among monolingual speakers of American-English. Pointing to data showing that most English speakers can describe all spectral colours with the four unique-hue names is pointless: they simply report on the current grammar of English colour words. Moreover, because of the spread of Western science, education and technological products, this ‘rule’ now encompasses the greater part of the world.

One might suggest that what is wrong with speakers of Kwakw’ala or Karam, is that their language hasn’t yet evolved to the ‘true’ basic cognitive categories. The suggestion would be that at the cognitive level there is a well defined innate colour space (three dimensions, six unique points). At the prelinguistic level the universal colour and its structure is present in all human brains. Due to local circumstances a language may fail to ‘map’ the universal categories, because it hasn’t evolved sufficiently. However, there is a scientifically and politically dubious character to this suggestion. Virtually all current speakers of Kwakw’ala are bilingual. They know perfectly well what the difference is *in English* between yellow and green, but they stick to one word in Kwakw’ala, *lhenxa*. For about a century now they have also been using *ayendzis* for orange, which most speakers recognise as a loan word; some speakers nowadays also use *pinkstu*, a neologism coined for ‘pink’. But yellows and greens are simply *lhenxa*. To suggest that *lhenxa* overlays the union of two unique colours (‘yellow’ and ‘green’) at a deeper (sub)cognitive level seems too much of a coincidence, viz. that the ‘natural’ categories at the deeper non-linguistic level are always those of modern twentieth century English. ‘Natural’ in this context merely rationalises the status quo.

Sect. 2.4. the boundaries of the colour domain

All discussions take for granted the domain of colour; it is ‘given’ - cognitively, intuitively, linguistically, formally. We have been raising sceptical doubts about its putative three dimensionality and the four unique hues. But the most important question is: Why are we talking about colour in the first place? There are skirmishes about the number of dimensions of

colour; disputes about what these dimensions are, and even whether we can properly talk about them in the first place. There are squabbles about whether there are four unique hues, and how they relate to colour invariances or alternative colour dimensions. There are conflicts about whether seeing red and green simultaneously is an empirical question. There are disputes about the (paradoxical) relation of six unique colours and eleven basic colour terms. And philosophers, and even psychologists, worry about inverted spectra and qualia. And so on. We could leave all that for science to sort out. The fundamental question remains: what grounds are there for thinking there is some special domain called 'colour'?

Tlapanec speakers (of Mexico) may, depending on (something like) the brightness of the sky, innocently refer to it in Spanish as being green (*cielo verde*), because their word *masha* is standardly translated as *verde*. A more charitable interpretation (by the lights of the interpreter) might be to say that *masha* refers to certain brightness levels in the blue-green-purple hue region. Similarly, the Paliyar in south India (who speak a Tamil dialect) have the words *velle*, *manja*, *nilam*, *sihappu*, *karuppu*, which are translated nowadays as white, yellow, blue, red, and black respectively. But before language was influenced through contacts with the rest of the world, better glosses might have been: brightly illuminated, bright, of medium brightness, rather dark, dark/shadowy. This is not to imply that their classification implicates a scale of brightness, but merely to stress that the brightness glosses, although no doubt crude, provide a better rendering (by our lights) than the hue glosses that were later imposed. Hence, it is not obvious that the salience of colour antedates all learning.

The examples in the previous paragraphs bear on the relative autonomy of hue and brightness. Now consider the language Arawak, where there's no separate colour domain, although there are words like colour words. There are three terms covering the brightness or intensity of light: *karimeto* 'dark/black', *harrirato* 'light/white', *subuleto* 'various medium bright colours, including yellow and light blue'. In addition Arawak designates hue aspects via what seems to be a vegetation metaphor, with three terms: *imoroto* 'unripe, immature, green, pale yellow', *koreto* 'ripe, mature, red, orange, deep yellow', and *bunaroto* 'overripe, overdone, brown, buff, tan, purple'. Are these people having ripeness quality spaces, colour quality spaces, hybrid spaces, or what? Are we going to say that speakers of Arawak use colour words metaphorically for degrees of ripeness? Or are they using words for degrees of ripeness as metaphors for colour words? Are such words homonyms, where the semantic division follows the 'universal' western categories? Or is raising such questions nonsensical?

What grounds do we have to consider the domain of colour to be autonomous and universal. Consider a plantation that looks red because of an abundance of fruits. What does somebody, standing on a nearby hill see down there? He or she perceives *beunga'i*. For a start, its worldly reference can be introduced with the following report by a human observer educated in the modern world:

seeing a plantation, with vegetation carrying an abundance of fruits of some sort, everything in the field of vision slightly vibrating because of the wind and thermal effects in the ambient air, a lot of red with purple and yellow tinges is salient (of course there is an abundance of green and blue in the field of vision as well, but one isn't aware of that directly), there is a mood of pleasantness; the skin feels good, the smell is right, the sound, the taste, the whole body feels right, 'things' are moving in the right direction ...

It would need great literary talent to convey a first impression of what it is to 'directly perceive' *beunga'i*. But any separation of *beunga'i* into a hue or colour perception, a smell in the air, an awareness of a process taking place, an experience of something pleasant or rewarding, a feeling of place, or whatever other components - such an analytic partition would be an artefact of the inferences of the interpreter, describing the direct perception of *beunga'i* in terms of primitives the observer fancies, has been trained to apply automatically, has borrowed from physics, or invents for the purpose of describing something not described before in the language of the observer.

Inferential descriptions introduce many discriminations and distinctions: objects, parts of objects, properties, relations, events, processes, evaluations, and so on. But in the direct report of *beunga'i* (being here/there/around), the distinction made by count and mass nouns, nouns and adjectives, verbs and their tenses is not given in a straightforward way - first there is *beunga'i*; then there is analysis and inference. Moreover, when one directly perceives *beunga'i*, there are not only manifest descriptive properties, but dispositions, potentials, affordances, attractions, threats. All are theoretical posits in the web of *beunga'i* and talk of posits in a web only arises after analysis of the direct pick up of *beunga'i*.

Hence, there is nothing natural or salient or intuitively obvious about, say, the difference between hue, lightness, and saturation, or the four unique hues, or considering the colour domain to be autonomous - unless one is used to English grammar

and its embodied saliences. It's not that 'saliences' are a property merely of a language or a mind. Saliences (such as 'fire red' and *beunga'i*) are certainly out there in the world. But the same situation or environment affords innumerable saliences: 'an ostensive definition can be variously interpreted in *every* case' (Wittgenstein). Which saliences are 'embodied' in language, cognition, or milieu depends on the socio-history and technology of its users. This doesn't make saliences such as *beunga'i* less objective. Red, green, *masha*, *lban*, *lhenxa* and *beunga'i*, are equally objective if learnt and applied in the appropriate lifeworld.

Drawing on examples such as *beunga'i* doesn't mean one cannot do 'hard' cognitive science. On a Gibsonian inspired approach, the direct perception of *beunga'i* might be described as follows. The patterns in the global array underlying the perception of *beunga'i* are sensed directly. They are not broken down at receptor surfaces and then reconstructed. The perception of *beunga'i* is not the outcome of a group of systems working in parallel (or in conflict), but of a single system, whose parts operate as a unit to pick up information that exists in irreducible patterns across different forms of energy. The pick-up of information is influenced by events, objects, surfaces and the continuous changings in the environment, as well as the perceiver's successful control of movements of receptor systems and of the whole body - even in the 'stationary, passive' observation.

The structure of the ambient array, resulting from this animal-environment interaction, is unambiguous with respect to the reality of *beunga'i*. The direct perception of *beunga'i* supervenes on a state of the world which gives rise to energy patterns, prior to and independent of sensory stimulation or any psychological process. The structured energy fields that are available to perceptual systems (the potential sensory stimulation) are sufficient, in and of themselves, for the accurate perception of *beunga'i*. Hence, the perception of *beunga'i* provides veridical information about reality which can be picked up without mediation by unconscious inference or anything else.

The world in which humans live is not a model of that world, stored in the brain. It is composed of general and specific purposes emergent in relational processes and is embedded in a social and moral order. Only in and through activities and their dynamic properties can what is seen become thematised as a focus of awareness or perception. Awareness or perception is not inert and passive, but active and exploratory. No mechanical ray enters the eye as a static object conveying 'information' to be sieved by the mechanical forms of thought. Rather the eye might be regarded as a temporally governed probing tool, that moves, checks and interacts with the other senses, the whole body and the animate and the inanimate environment. Or, to put it more strongly, the strict separation of the senses introduced by Aristotle, might have to be left behind: each perception and action interacts at the physical level with several perceptual systems.

Sect. 3 ORIGIN OF COLOUR

Sect. 3.1 Isomorphy thesis

Two basic assumptions in these discussions are never addressed:

- 'colour' is a 'given', a natural kind, a modular domain, a well-determined universal category;
- the phenomenal or perceptual 'colour space' has a well-determined structure which allows it to be described in terms of a small number of dimensions and/or primitive notions.

The history of philosophy and science has made it difficult to imagine otherwise. However, as we have seen in parts 1 and 2, the above two assumptions are in no way self-evident. The received view concerning colour corresponds to the following assumptions underlying much of cognitive science and naturalistic philosophy.

- There are a number of cognitive domains, each containing a fixed number of culturally (or even species-invariant) and discontinuous basic categories. All the domains together make up one closed system.
- All action/behaviour fits some cognitive model or other. Cognition is, so to say, just a quantity of stuff for which the scientific laws, giving its statics and dynamics, need be found.
- Any (cultural, linguistic, historical) variation is merely a veneer covering the underlying innate cognitive structure.

The ‘star example’ exemplifying this picture, is colour. All colour discussions, whether in the philosophy of mind, epistemology or elsewhere, share a background of what might be called ‘the isomorphy thesis’: what we perceive, experience, think is a representation of what is the case or what is happening in the world.

That is, using red and green as examples:

- in the physical world there are natural kinds, for example red and green;
- in the mind there are psychological primitive ideas, mental representations, innate categories, types of experiences, or ‘quales’, for example red and green;
- primitive categories are represented in the neurophysiology of human brains, for example in red- and green-sensitive opponent cells in the cortex;
- all languages draw their basic colour categories from the same inventory of linguistic universals, such as RED and GREEN.

The isomorphy thesis tells you there is a one-to-one isomorphic correspondence between ‘levels’. It matters not for the general picture how many levels there are, what they are called, at what level investigation starts, and so on. According to the isomorphy thesis there is always already a distinct link between language, thinking, and world. This isomorphy is a pan-human universal, at least for red and green.

Sect. 3.2 The pull of popular theory: eleven basic colour terms

Apart from the pull of the isomorphy thesis, there are at least two more specific reasons for the apparent robustness of colour:

- Due to the ‘bewitchment’ of colour as we know it, the history of colour science is full of proposals for simple theories appealing to variants of the isomorphy thesis, based more on a priori standards and models than on empirical evidence. Moreover, results have been excessively generalised. We’ll call this phenomenon the pull of popular theories and briefly discuss one, namely that of Berlin and Kay’s theory of eleven basic colour terms.
- Perhaps even more important, due to globalising processes, there has been adaptation of periphery to centre. In section 3.3 examples are given of how missionaries, linguists, and anthropologists regimented the world’s languages and how the forces of colonialisation and globalisation finetuned the periphery to the centre. In addition we draw attention to the ethnocentric bias of research based on whatever is measured ‘on’ American students or ‘colleagues’ considered representative of humanity.

In many disciplines Berlin and Kay’s book *Basic Color Terms* is cited as support for the cross-cultural universality of a fixed number of basic colour terms (BCTs). Their stated goal was to refute relativism. In its place they proposed that all languages had words referring to the same two to eleven foci. The claim to universality was based primarily on the clustering of these foci across twenty languages investigated with Munsell colour chips. These experiments were further amplified by data on seventy-eight languages gathered from dictionaries, ethnographies, and personal communications. A fixed, unilinear evolutionary sequence prompted by environmental triggers explained why not all languages automatically contained eleven BCTs. This evolutionary sequence has been likened to ‘a primary epigenetic rule serving colour category development’ and has been reproduced in enumerable publications.

Berlin and Kay assumed there was a perceptuolinguistic basic colour system which is innate, biologically constrained and (semi-) automatic. In the absence of any reason to suspect members of other speech communities having different automatisms, they felt justified in taking the American English colour lexicon as a standard. Experiments were set up in such a way that utterances or speech acts could be transposed into BCTs through a procedural rule of translation. This revealed that at the meta-level, as in American English, there were exactly eleven BCTs. Although it is suggested that BCTs were the *result* of cross-cultural empirical research, this lexicon was indirectly derived from the most popular American-English colour terms in the 1944 *The Teacher’s Word Book of 30,000 Words*. Like the belief in four unique hues, the belief in eleven BCTs takes for granted the autonomy of colour. Elsewhere we’ve discussed the theory of Berlin and Kay and its later emendations. Here we’ll hint at some of the problems.

Despite the general acclaim for the theory, most detailed reviews of Berlin and Kay were critical of their methods of gathering and/or presenting data. There is an appearance of sloppiness which cannot but reduce one's confidence in their conclusions. Apart from printing errors and mislabelled colours in the mapping diagrams, there were also ethnographic errors and phonemic mistranscriptions. No straightforward information on the informant sample was provided and the choice of languages was not justified. In their use of data from the literature, Berlin and Kay seem to have used whatever came to hand; no distinction was made between referential and attributive use, or between the empirical and the eternal. Of the 20 languages for which Berlin and Kay gathered data, 19 were represented by one bilingual speaker only, living in the San Francisco Bay area. This left out of consideration from the start any cross-cultural significance. In reviewing the methodology and nature of the data, one reviewer concluded: 'the reliability and validity of the experiments are zero'. Further, several critics pointed out that the restrictions on the BCTs remove most of the world's colour vocabulary. Moreover the defining criteria for BCTs are extremely plastic and because of the fluidity of the rules, data manipulation is easy. Finally, alternative explanations of tendencies to basic colour categories across languages were not been considered.

From the outset the assumption was made that the instrument used to gather data, viz. the small plastified cardboard 'chips' exemplifying 320 saturated colours plus nine achromatic chips from the *Munsell Book of Colours*, defined exhaustively what colour is. The 'operational' definition of a BCT together with the extraction rules organize responses and data. These are standardized to conform to the ideal language of the colour space, thereby removing everything of the contingent and historical setting. Procedure is imposed on 'observers', a common currency is produced, and regularity is emphasized in anticipation of the evolutionary rule. A piece of Nature is standardised by the Munsell system and projected as law-like, mathematical and *a priori*, validated by evidence gathered under conditions approximating the laboratory. Every 'fact' is regulated in terms of this project, so that 'nature' can be described as exhibiting itself 'objectively.' But the system and its methods determine in advance how 'facts' are to relate to one another, to the 'observer' and to the object of knowledge.

On a simplistic view Berlin and Kay's theory is subject to immediate 'falsification' (in the Popperian sense). For example Bickerton), while endorsing Berlin and Kay, says:

Spatiotemporal contiguity, although a necessary condition on [colour] naming, is not a sufficient condition. If it were, some language would have a word *yeen meaning 'yellow and/or green' ...

However, Kwakw'ala, along with other languages on the Northwest Pacific Coast, Africa and Australia, does have a word for 'yeen', viz. *lhenxa*, that is: there are no individual words for green and yellow.

The original Berlin and Kay evolutionary sequence cannot accommodate a 'yeen' category, though its existence has been known in the literature at least since the 1880s. In some cases information about 'yeen' terms was lost because of change due to interaction with Western technology and lexicographers. But it is precisely because of these changes under the influence of the dominating Western culture that 'revisiting' any such cultures with sophisticated experimental techniques will do no more than confirm the existence of dominance (section 3.3), in so far the outcome isn't already predetermined by the techniques used.

As we indicated above, the results of Berlin and Kay are foreclosed, as an *a priori* given, by restricting 'colour' to 329 chips from the *Munsell Book of Colours*. Each plastified cell on the chart presents the model or prototype of the relevant 'sensation' of hue, saturation, and brightness. Putting aside the plausibility that the notion of 'sensation' itself is meaningless, it is by definition not something that can be measured. However, and this is the mystical touch: colour measures reality as it *really* is - cf. the Machian or Carnapian dictum that the world of colour orders and measures reality.

Why does it nevertheless seem to many that there is ample support for the thesis of Berlin and Kay? First, because the pull of progress is so great that critical awareness of 'data cleaning' is suppressed. Second, because the theory appeals to a deeply ingrained isomorphy thesis that places sensations (or 'sense data') between world and thought between physical causation and epistemic beliefs. The direct 'experience' of the 'percept', 'sensation' of 'sense datum' of, say, RED, guarantees the truth of its isomorphic presences in the world, cognition, and language. The Munsell system, aperture mode experiments, and 'Mondrian'-experiments are latter-day embodiments of this picture theory of perception.

Though numerous criticisms have been levelled at the Berlin and Kay theory and in later publications almost all of the original claims have been withdrawn, textbooks continue to spread the gospel.

Sect. 3.3 Linguistic regimentation and the adaptation of periphery to centre

For about a century, linguists have been busy regimenting the (remaining) languages of the world and for an even longer period languages have been accommodating themselves to the dominance of western colour technology and terminology, thereby offering cross-cultural autonomy to its domain. It is to this centre - periphery force field we now turn.

Let's look at *lhenxa* one last time. First, the most important question is *not* whether speakers of Kwakw'ala use one word (*lhenxa*) for something twentieth century European languages divide into two (green and yellow), but whether or not it is *the same* that is divided into two.

Now let's see how *lhenxa* has been translated at various times. Between 1892 and 1947 there are five sources translating it as 'green'. Imagine that Kwakw'ala would have disappeared - not an implausible hypothesis: every year many languages die out. Had Kwakw'ala disappeared, linguistic practice would have eternally fixed that *lhenxa* meant green. Apparently Boas assumed that necessarily Kwakw'ala had a word for green. For yellow he gave the root *moxw*-. Kwakw'ala speakers asked about this word in 1990 had never heard of it.

Examples such as these are rarely critically examined. Instead authors tend to take the data at face value, without situating it in a context (colonial history, globalisation or centre - periphery force fields). The presumption that the human brain is hardwired to speak English is all pervasive.

Sect. 3.4. Developmental trajectory of colour - an exosomatic organ?

The colour talk of philosophers and psychologists concerns what goes on in a very particular laboratory world. Calibrated colours are then exported into the lifeworld in material form (technological products, Munsell chips) and as 'intuitions' (the innate or intuitive 'neo-Kantian' colour space).

To make 'colour' the phenomenon it is, is to define it in a specific way, under a particular description, by removing from the experimental setting everything but the realisation of a purified 'stimulus', characterised in (physical) CIE-terms. Relegating 'context' to the periphery, the phenomenon so defined by contextless procedure, is placed at the core. Standing behind these procedures, is the notion of a colour space, which is the powerful theoretico-mathematical device that ratifies the procedures, objectivises the data, and reinforces the production of colour as an isolated phenomenon. Networks of different levels of theory constitute the truth-producing apparatus which produces the phenomenon. By mutual adjustment of phenomenon and frame, a purified laboratory phenomenon - colour - emerges and is declared 'true to' the world. The frame itself is true to prior framing devices: the construction and use of instruments, and the dialectic of theories and practices. Observation and measurement are conducted with apparatus that co-evolved in conjunction with the phenomenon *as seen through* these observations and measurements and concomitant modes of data analysis. As a result colour science explores the (changing) definition of the colour science system itself.

The laboratory context detaches objects from their natural environment, processes partial versions of the phenomena, enhances that environment, and improves on natural, relative to social orders. That context installs and reconfigures new phenomena, which are defined by scientists. This involves cleaning up the data (correcting instrumental artifacts, sharpening contrasts, upgrading figural identities, making data look 'natural', coding and plotting it on 'arrays', selecting 'good' illustrations for publication). What starts as a process of reconfiguration may develop into replacement and redescription by 'completely' new items through a manifold of interacting processes. These newly discovered/invented items are then exported into society, where they are further reconfigured and may be given new meanings in the prevailing lifeworlds.

What explains the pragmatic success of colour science? One answer is that the environment is remade by paints and dyes, reproductive technologies, coloured lights, advertisements, fashion, television, cinema, computer screens and so on, in such a way that it reproduces the theory of colour that provides the techno-material base for the production of the coloured world. The world then becomes a quasi-laboratory in which it is neither 'truth' nor 'world' that explains what makes colour science work, but the world which is remade in the laboratory. 'Co-production' of colour science and 'colour' therefore stresses that what is currently called 'colour' is inseparable from its processes of manufacture in the laboratory and pragmatic realisation

in 'the world.' Colour-in-the-world is a co-production of colour science, laboratory, and the techno-scientific bases of raw materials and commodities. In this way the 'truth' of colour brings its objectification into the world by mobilising the resources of this techno-scientific grid. There is a reciprocal relation between evolving modes of perceiving and the evolving philosophy, science, and technology of colour.

Why is it that the standard colour story, *prima facie*, sounds so convincing? Perhaps the ordering of colour in terms of a three dimensional space and the appeal to four unique hues or eleven basic colour terms should be understood as the result of the development of an exosomatic organ. The notion 'exosomatic organ' finds its origin in Hegel's insistence on objectification and expression as conditions of becoming and of humanisation. It was later developed into the view that exosomatic organs have their own historical trajectories that ground the variability of perception and apprehension. An exosomatic organ is a tool, which substitutes for, extends or compensates for the inchoate powers of the human body (like print, microscopes, telescopes and computers). More generally, it refers to institutionalised structures that replace and extend potential capacities of the human brain and body. Just as alpha-numerical systems alter and extend the powers of calculation and theorisation, so too colour (and space), as understood by science, recursively alter and extend the powers of vision.

In this way stable classification spaces, such as 'the' colour space, become entrenched. The tool and skill become so interiorised that a change in the habits of existence is brought about. Those exposed cannot avoid being subject to its operational conditions. Once brought forth in technological form, the exosomatic organ-space feeds back into and conditions its originating universe and mode of awareness.

Sect. 4 CONCLUSION

To 'see colour' is a technique that has been learned through training: a modern scientifically and technologically grounded skill that focusses on particular well fixed distinctions in the exosomatic colour space. The colour-units of technological products such as paints and dye stuffs, artificial light sources, TV and computer screens, as well as their underlying standardisations, are built into the scientifically constructed colour space. Consciousness picks up this order through exposure and training. In this way a stable network has come into being for colour perception. The skills and techniques become so interiorised that experimental research merely confirms the 'truth' of the framework.

For colour to become visible, it must be an institution, a consolidation and sedimentation, evolved from a basis in direct perception, which feeds back into, and modifies both the world as well as our ways of looking. Once the idea of the closed system of basic colour categories or opponent unique hues is in place, metaphysical precept, optical habit and daily practice combine to incorporate back into the visual universe just that which they were developed to organise and describe. The entire history of visualised-verbalised packaging of *objects* and *appropriate viewing conditions* then provides the 'information base' for colour perception. Sensitivities to the constantly changing patterns of light frequencies and intensities spread out on the retina, are transmuted by structural mechanisms into categories in the 'colour space' and then projected back as a skein or envelop of chromaticity over the world. So the colour space is both a model of the 'colour space' in the brain *and* a model of colour in the world, as the isomorphy thesis requires. Bootstrapped together with the standardised production of pigments and dyes, this base becomes systematised and codified into the ontology we call 'colour'.

The deep claim and distinguishing feature of the colour space is its capacity to split the unity of living in a chromatic world. Once unity is dissolved, *the reality* of the model comes to be confused with *the model* of reality, and by a kind of *Aufhebung*, the model comes to be seen as a higher form of reality - as the *concept* or *representation* or *computational rule* of colour in the brain. Colour is then deconstituted and reconstituted solely in terms of that model, which then starts to live a life of its own. Consequently what can be said about the model exhausts what can be said about colour.

REFERENCES

This paper is an extract from a longer text, which is based on a few hundred references. See for further discussion and references to the original sources:

- Saunders, B.A.C. and J. van Brakel (1997) Are there non-trivial constraints on colour categorisation?, *Behavioral and Brain Sciences*, 20: 167-232.
- Saunders, B.A.C. and J. van Brakel (eds.) (2002) *Theories, Technologies, Instrumentalities of Colour: Anthropological and Historiographic Perspectives*, University Press of America: Maryland, forthcoming.