The dual coding of colour: *'Surface colour'* and *'illumination colour'* as constituents of the representational format of perceptual primitives

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Colour is one of the most conspicuous aspects of visual experiences. Together with shape it imparts objects their individual distinctiveness and is a salient characteristic of the appearance of objects. Whereas shape is a property of physical objects that seems to be intrinsic to them, apparently a necessary part of their physical description, the nature of colour seems to be much more enigmatic. On the one hand, colour experiences are by and large tied in a lawful way to physical properties of the 'external world', on the other hand, colour experiences have a peculiarly subjective nature. Though the structure of our entire phenomenal world of perception is, in a sense, brought forth by the internal conceptual structure of the brain, we tend to ascribe different degrees of objective and subjective origins to its different aspects as a consequence of this conceptual structure. Colours fall right on the boundary that we have drawn by bifurcating the world into the physical and the psychological; more than other perceptual attributes, they seem to be Janus-faced. This is also mirrored in the incoherent and vacillating linguistic usage of colour expressions in everyday language (for instance, we can speak of an object as looking purple though being blue or as having lost its colour). Our everyday usage of colour concepts hovers between two quite different meanings of colour, to wit colour patches and colour experiences (which has given rise to tremendous philosophical confusion). This ambiguity, with respect to the entities colours are ascribed to, does not, however, prevent ‘colour’ being conceived as a kind of autonomous and independent attribute in common-sense taxonomies. Scientific inquiry, however, has to go beyond common-sense taxonomies – here as elsewhere in the natural sciences – and to pursue lines of inquiry that are dictated by attempts to develop explanatory frameworks of interesting range and depth. In scientific investigations ‘colour’ does not demark a single field of rational inquiry or a unitary explanatory domain. Questions centring around colour phenomena can, for instance, refer to abstract theories of perception, to the minutiae of neurophysiological coding, to the evolutionary history and functional role of colour perception, to the role of colours in animal communication, to dyeing techniques in arts and industry, to aesthetical or emotional effects, or more generally to common-sense psychology and common-sense physics. Each of these domains has its own specific goals and prompts different questions to be asked. Detached from specific domains of inquiry, attempts to ascertain what the essence or 'quidditas' of 'colour' is, are thus pointless and of no relevance for any of these domains. Notwithstanding that scientific inquiry ultimately strives, wherever possible, toward explanatory unification over different domains, jumbling up different explanatory goals and different levels of analysis in colour perception may veil problems of theoretical importance and hinder a theoretical understanding of the perceptual principles on which it is based.

If we, more specifically, turn to a more narrowly defined domain of inquiry and try to develop abstract theories that describe the role ‘colour’ plays within the basic architecture of our perceptual system, we are again tempted by common-sense taxonomies to regard ‘colour’ as a kind of autonomous and independent attribute that can be investigated more or less in isolation. A proper acknowledgement of relevant facts and observations leads, however, to a quite different theoretical picture: contrary to what common-sense taxonomies suggest, ‘colour’ is not an autonomous attribute and cannot be studies detached from other aspects of our perceptual architecture. Corresponding pre-conception - still highly influential in colour science – that, with respect to our perceptual system, ‘colour’ is a single and autonomous attribute, have greatly impeded the development of appropriate explanatory accounts of perception.

Technology-Shaped Refinements of Common-Sense Taxonomies

Among the biggest obstacles for theoretical inquiries into the internal perceptual structure underlying colour perceptions are what Evans (1974, p. 197) called the "errors of the application of colorimetric thinking to perception", i.e. inappropriate use of abstractions and concepts that were developed, as refinements of common-sense taxonomies, to serve purposes of colour technology. Because these abstractions, particularly those that are presumed to capture 'basic attributes' of colour, seem quite natural from the point of view of our ordinary way of talking about colour (which itself has been modified by a technology-shaped progression toward an increasingly abstract colour vocabulary) they were also considered as the natural and almost compulsory point of departure for dealing with colour within perception theory. Their apparent cogency was augmented by selecting specific types of colour phenomena and experimental settings that seem to speak in favour of the corresponding abstractions being particularly revealing for the nature of colour perception. As a result, these conceptual frameworks have impeded the identification of types of phenomena that mirror core colour-related aspects of the structure of internal representations. The apparent cogency of these conceptual frameworks, which were taken as a matter of course in perception theory, was furthermore fed by a widespread general misconception of the nature of perception that perfectly fits in with these frameworks, namely the measurement-device misconception of perception (which, in turn, is intimately connected with empiristic preconceptions about the structure of the mind). According to this conception, whose core is itself part of common-sense reasoning about perception, the perceptual system is some kind of measurement-device that has to inform us about elementary physical quantities. [1]

Due to these ways of conceptualising perception, attempts to theoretically understand the role of colour within the structure of perceptual representations have been severely hindered by the merging of two lines of thinking that have their roots in common-sense conceptions, namely abstractions derived from technology-shaped refinements of common-sense taxonomies and the measurement-device misconception of perception. Approaches based on these lines of thinking have become, despite their utter inadequacy, the dominant paradigm in perceptual research on colour. This is due to the fact that they appear, from the perspective of our everyday way of dealing with colour, intuitively plausible and that they provide, together with suitably selected phenomena and experimental procedures, a framework that appears to be quite coherent when the focus is primarily on colorimetry and the neurophysiology of early coding.

The fact that this apparent coherence has been bought by concealing core aspects of the role of colour within internal representations becomes obvious as soon as the vast theoretical distortions that accompany these lines of thinking, when dealing with core perceptual phenomena, are recognised. Before I delve into these in more detail below, a simple example may serve as an illustration, namely the issue of so-called object colours, such as brown. As a typical quote from the perception literature, Boynton (1975, p. 316) remarked that "the sensation of brown arises *de novo* by induction from the surrounding field"; obviously colours like brown are regarded as less 'original' than the 'primordial colours', such as red, orange, yellow or blue, which are considered to be closely tied to the wavelength composition of the light and thus, as suggested by this formulation, do not arise *de novo.* This way of distinguishing between 'original colours' and colours that "arise *de novo*" reflects a variant of the measurement-device misconception of perception according to which "the visual system is concerned with estimating the spectral functional shape of the incoming color stimulus." (Buchsbaum & Gottschalk, 1983) In the case of brown, the 'original colour' is taken to be a dark orange, which, due to its surround, is 'modified' to yield the "dark orange that we call 'brown'" (Boynton, 1971, p. 368): a rather odd formulation which provides evidence of the theoretical distortions produced by the underlying conceptual framework. Since these enigmatic modifications, which are assumed to produce new kinds of colour *de novo* from 'original colours', cannot be accommodated within this framework, one has to retreat, as for instance Judd (1960, p. 257), to unspecified "different modes of processing" of retinal colour signals "in the central nervous system." In contrast, current functionalist-computational approaches and their philosophical aftermath often are accompanied by a distal variant of this misconception according to which "the goal of colour vision is to recover the invariant spectral reflectance of objects (surfaces)." (Poggio, 1990, p. 147)[2] Those colours are, accordingly, regarded as 'original colours' that are closely tied surface reflectance characteristics. Thus, brown is regarded as an 'original colour' rather than arising *de novo* because, like other colours, it is to be identified with spectral reflectances of surfaces that exhibit this property.

‘Colour’ and the Structure of Representational Primitives

In this chapter I will approach ‘colour’ from the perspective of cognitive science, which has, in various of its subfields, marshalled convincing evidence that our mental apparatus is, as part of our biological endowment, equipped with a rich internal structure pertaining to e.g. structural knowledge about properties of the physical world, distinguishing between physical and biological objects, or imputing mental states to oneself and to others. With respect to perception theory, this evidence indicates that the structure of internal coding is built up in terms of a rich set of *representational primitives*. Rather than asking what colour really is, or making presuppositions about its 'proper causal antecedents' or about the 'proper intentional objects' of colour, I will focus on how it figures within the structure of representational primitives of perception. Notwithstanding that we are still far from having a clear theoretical picture about the kind of primitives that underlie perceptual representations, primitives that refer to classes of internal entities such as 'surfaces', '3D-objects', or 'events' (to be understood as *internal*, and not as physical concepts) suggest themselves as fundamental pillars of the internal representational structure of perception. These primitives determine the data format, as it were, of internal coding. Each primitive has its own proprietary types of parameters, relations and transformations, which define their internal structure and govern its relation to other primitives. While colour as such is a biologically given part of the form of our experience, the role colour plays within the conceptual structure of the perceptual system and within perceptual architecture is open to rational inquiry. The evidence bearing on the role of colour within the structure of perceptual representations is enormously rich. Experimental observations and findings, phenomenological observations [3] on the interplay of surfaces and (chromatic) illumination as well as corresponding physical considerations provide a rich source for theoretical conjectures about this role.

Current thinking in perceptual psychology has predominantly focused on *processes* of information flow and has paid little attention to explicitly addressing the problem of the *structural format* within which the internal coding processes take place or to identifying the primitives on which complex perceptual representations are built (corresponding questions rather have often been trivialised by preferences for thin sets of quite elementary primitives). A similar diagnosis holds for cognitive psychology in general where "one typically finds rather perfunctory discussion of information structure only as a prelude or postlude to extensive treatment of processing." (Jackendoff, 1987) An essential task of perceptual psychology thus continues to be the identification of the primitives of the internal conceptual structure of perception, of their 'data structure' and of their associated proprietary types of transformations that operate on these primitives. While not much is presently known about the structure of the representational primitives, evidence has been accumulated supporting the idea that quite different representational primitives include free parameters that can be characterised as pertaining to the attribute 'colour'. If 'colour' figures in different kinds of representational primitives, one can hardly expect to understand its internal structure by investigating it in isolation. 'Colour' is not a 'natural kind', as it were, of internal processing, i.e. it is not a class of explanatory importance of internal states or processes that are held together by the same set of properties. In common-sense taxonomies, in contrast, we have come to regard 'colour' as a kind of autonomous and independent attribute. A major obstacle to gaining a deeper understanding of the role of 'colour' in the internal conceptual structure of perception is that we illegitimately transfer common-sense reasoning about colour to scientific inquiry of perception. I will, consequently, argue - in line with Koffka's insight that "colour, localization, shape and size must be regarded as different aspects of one and the same process of organization" (Koffka, 1936, p. 134) - that attempts to identify the representational primitives of the structure of perception and their 'data structure' by investigating attributes like colour (or depths, etc.) in isolation are doomed to fail (apart from lucky coincidences). This is just as problematic as trying to determine an n-dimensional manifold from a random sample of one-dimensional projections. Rather, questions about colour perception can only be formulated within theoretical frameworks that explicitly address the nature and structural relations of the primitives of perceptual representations in which colour figures.

A general theoretical approach that I believe to be well-founded in its general conceptions and that has already yielded intriguing explanatory frameworks of promising range and depth, notably when couched in computational terms, is an ethological and internalist one. Corresponding approaches attempt to provide explanatory accounts of the perceptual system in terms of its *internal* functioning; they employ, with respect to visual perception, a level of analysis that focuses on how structural properties of the physico-geometrical light pattern reaching the eye (which can have been causally generated by quite different physical processes) are exploited by the visual system in terms of its primitives. No notions of reference to the environment, 'proper function', etc. figure in these approaches, which consider notions like 'perceptual error' or 'veridicality' to be of little relevance for understanding the internal structure and functioning of the perceptual system (though they are an indispensable part of ordinary or metatheoretical discourse). [4]

The general approach to colour that I pursue here has, in its core elements, a long history in perception (cf. the Appendix in Mausfeld, 2002a). However, apart from a few exceptions in the early twentieth century, research perspectives in colour science have followed different routes of thinking. The driving forces in the field have been attempts to understand the (early) neurophysiological coding of colour and issues of colorimetry (cf. Koenderink and van Doorn, this volume). The influences of these fields resulted, in perceptual psychology, in an extremely elementaristic perspective on colour that allied itself with a measurement-device misconception of perception. Both the elementaristic perspective and the measurement-device misconception of perception (a variant of which also showed up in functionalist-computational approaches) have hampered the general approach pursued here from being applied to colour. Since I have dealt with these issues elsewhere (Mausfeld, 1998, 2002a), I will restrict myself to addressing two specific consequences of these general obstacles, namely misconceptions about the 'basic attributes' of colour and the neglect of illumination-related issues in colour research; furthermore, I will address a third obstacle that lies in the conflation of different levels of analysis. What I intend to point out can be summarised as follows.

Obstacles to an Appropriate Account of the Role of 'Colour' within Perceptual Architecture

The alleged basic attributes of colour, usually referred to as hue, saturation and brightness, as well as associated notions of a three-dimensional colour space, are theoretical notions that arose as abstractions from technology-driven refinements of common-sense taxonomies. Their usefulness is confined to the purposes for which they were developed, namely colour technology and colorimetry. With respect to perceptual psychology and its aim to understand the internal structure of colour representations, these theoretical notions and the general perspective underlying them have prevented the right questions being asked and impeded the development of appropriate explanatory frameworks for colour perception. In particular, they are responsible for issues of illumination perception largely being neglected (or trivialised by what may be called the adaptational perspective), and subsequently being addressed, in a mis-idealised way, as the problem of colour constancy.

The properties of the external world that causally give rise to the physico-geometrical structure of the sensory input, on the one hand, and the relations between properties of the sensory input and the internal outputs or percepts of the visual system, on the other hand, are two utterly different problems that need to be distinguished carefully. Therefore, the core question of perception theory, viz. how are structural properties of the incoming light array exploited by the visual system in terms of its primitives, must not be conflated with the question, what properties of the environment give rise to perceptually relevant properties of the incoming physico-geometrical light array. Because of this, notions of 'reference' or 'veridicality' do not figure in perception theory proper but pertain to a different level of analysis (and are also part of ordinary and metatheoretical discourse about perception).

Summary of Main Theses

I feel that a useful step would be to deal with these obstacles in some detail in introductory sections before turning to a general ethological and internalist approach to perception. After having introduced this general framework, I will deal with some specific questions about the role ‘colour’ plays as a constituent of the representational format of perceptual primitives. The main theses I shall argue for in this chapter can be summarised as follows.

1. Within an ethological and internalist account of perception, a categorical distinction is made between a sensory system and a perceptual system. The sensory system deals with the transduction of physical energy into neural codes and their subsequent transformations into codes that are 'readable' by and fulfil the structural and computational needs of the perceptual system; its internal concepts are entirely definable in the same physico-geometrical language that we use to describe the sensory input. The perceptual system, on the other hand, contains, as part of our biological endowment, the rich perceptual vocabulary, which is based on primitives that cannot be defined in terms of the primitives of the sensory system, in terms of which we perceive the 'external world'. Furthermore, the perceptual system provides the computational means to make these perceptual concepts accessible to higher-order cognitive systems, where meanings are assigned in terms of 'external world' properties.

2. The sensory codes serve a dual function: firstly, they provide triggering cues for representational primitives and thus they determine the potential data formats in terms of which input properties are to be exploited. Secondly, they are used by the activated primitives to determine the values of their free parameters.

3. Colour figures as a free parameter in the structure of (at least) two different representational primitives that, from a metatheoretical perspective, can be regarded as pertaining to the representation of ‘surfaces’, and the representation of ambient and local illuminations (note that within an ethological and internalist account, the term ‘representation’ only refers to postulated elements of internal structure and does not involve any notion of reference to the external world). Consequently, 'colour' does not constitute, as common-sense taxonomies suggest and as most of current research presupposes, a single domain of an autonomous attribute but is rather a constituent of the format of different representational primitives.

4. The interdependencies in the data structure of representational primitives do not simply mirror corresponding physical regularities but rather are co-determined by internal aspects, such as internal functional constraints and internal architectural constraints. Because of this, internal concepts, such as

'surface colour', defy definition in terms of a corresponding physical concept (even in the sense of the latter providing necessary and sufficient conditions for the former). Rather, as corresponding empirical evidence indicates, 'colour' is dependent on the entire structure of the types of representational primitives in which it figures and on their interrelations, and cannot be studied independently of them.

5. The sensory system pre-processes the retinal colour code for the structural and computational demands of the relevant representational primitives. It provides a variety of relations on and transformations of retinal colour codes on which decompositions of the retinal colour code into a dual colour code can be based that fulfil the demands of the representational primitives involved.

First Obstacle: Misconceptions about attributes of colour and 'modes of appearance'

I will first draw attention to some of the factors that have so greatly impeded appropriate questions about the role of 'colour' within the structure of perceptual representations being asked, questions that had been clearly identified at the time of the Gestaltists, within the limits of the conceptual apparatus available at that time. Though, in the earlier literature, there was an awareness that colour does not mark a homogeneous domain with respect to core internal structure, this has almost been forgotten in approaches that have dominated the field since then. It is quite surprising to what extent we have lost sight of these previous insights. The main reasons for this development appear to me to lie in the following facts: Firstly, in line with empiristic approaches to the mind, perceptual psychology predominantly pursues an elementary data-processing approach and is still loath to address issues of representational primitives and the 'internal semantics' of the perceptual system . Secondly, investigations into colour perception tend to employ conceptual frameworks that have been established for technological purposes.

I will begin by recalling a few basic facts about the laws governing matches of small spots of light in otherwise dark surrounds. These matches can be described by the well-known linearity laws of additive colour mixture, often referred to as Grassmann laws. Because of the validity of these laws equivalence classes of lights that cannot be distinguished perceptually can be numerically represented by a three-dimensional vector space. Such numerical representations of metameric matches do not say anything about the colour appearances (except about the distinguishability-indistinguishability aspect) of the points of this space, which represent equivalence classes of metameric lights. In other words, there is no natural way of assigning colours to the points of this space. In particular, this vector space does not represent equality or inequality of colour attributes like hue, saturation, and brightness. The ratio of the length of two vectors does not correspond to a ratio of brightnesses, and a line in this space does not necessarily correspond to a constant hue. The empirical fact of trichromacy, on which the three-dimensionality of the representing vector space is based, only means that no more than three degrees of freedom are needed to match the colour of an isolated light patch; it does not, however, say anything about whether a coordinatisation of this vector space exits that corresponds to a set of 'basic attributes' of colours or that can be described in a natural way.

Hue, Saturation, and Brightness

Because the geometrical representations associated with these numerical representations of metameric matches exhibited a certain similarity to the geometrical representations of colours in colour order systems, such as the Munsell system, it was apparently tempting to describe them in terms of special co-ordinates that are assumed to capture basic colour attributes. The attractiveness of this way of linking Grassmann representations of metameric lights with geometrical representations of appearance in colour order systems is further enhanced if the alleged basic colour attributed could be operationally defined by simple physical operations. This explains why, since Helmholtz, hue, brightness, and saturation, which can be derived from the corresponding physical operations of selecting a wavelength, increasing light intensity and diluting a light stimulus with white light, have been chosen as basic colour attributes. [5] These attributes, which are usually regarded as a natural, unique and complete classification for describing colour appearances (see e.g. Judd, 1951, p. 837; Palmer, 1999, p. 97), are typically defined as

brightness:	“the attribute of a visual sensation according to which a given stimulus appears to be more or less intense” (Note the ambiguity of the concept 'intense' in this description.)
hue:	“the attribute of a color perception denoted by blue, green, yellow, red, purple, and so on”
saturation:	“the attribute of a visual sensation which permits a judgment to be made of the degree to which a chromatic stimulus differs from an achromatic stimulus regardless of their brightness” (Wyszecki & Stiles, 1982, p. 487).

Helmholtz and von Kries, who basically introduced this description, were aware that it is a completely arbitrary one in terms of essentially *physical* categories. However, for example, von Kries preferred to trade psychological arbitrariness for an apparent precision of colour concepts that results from their strong tie to physical operations. He remarked that a division of colour appearances in terms of hue, saturation and brightness "does not claim to be a natural one; without much ado we can regard it as a completely arbitrary one. Such a description is, however, a completely rigorous one, since it only refers to objective properties of the light that causes the corresponding appearances" (von Kries, 1882, p. 6).

In the early literature many writers clearly recognised the problems that arose from using elementary physical categories as a surrogate for perceptual ones (e.g. Hering, 1920, p. 40; Stumpf, 1917, p. 86). From the time of Helmholtz to the present day controversies have raged about how to appropriately choose 'basic colour attributes' and about how many of them are needed to capture essential aspects of colour. These controversies are not simply about terminology but rather have to do with intricate theoretical issues and differences in theoretical perspectives. Evans (1948, p. 39) spoke of "chaos in this matter" and went on to say that "the beginning reader in the subject can have little idea of how confused the subject has been in the past." If colour experiences could be carved up into basic attributes of hue, saturation, and brightness in a way that is as conspicuous and obvious as it is often presumed to be today, such chaos would hardly be understandable. I will mention only a few examples of these controversies about how to properly abstract what can, in the context of certain aims and purposes, be regarded as basic attributes.

According to Evans (1948, p. 39), "the most confusing word which will be encountered is brightness." Though, for isolated colour patches viewed in a dark surround such an abstraction does not seem problematic, its inadequacy already becomes obvious in what Evans called the "simplest configuration" for capturing essential qualities of colour, namely centre-surround situations. Observations in these cases led Evans (1974) to claim that *five* independent variables of perceived colour are needed to capture basic attributes of colours; among these he considered "brilliance" an essential attribute, which he understood as the surround-dependent amount of positive or negative greyness, the latter also being described as apparent fluorescence or "flourence" (Evans, 1974, p. 99). [6]

Centre-surround situations suffice to yield appearances such as luminous grey. Aspects of 'brightness' and 'greyness' are thus phenomenally dissociated, which in itself is a phenomenon of great theoretical relevance. It has been known since Hering that one needs at least two independent variables to capture aspects of achromatic colours. In reflections on art, the difference between a 'brightish white' and a 'whitish bright' is crucial and has been recognised as such ever since painters became interested in representing the effects of light (Schöne, 1954, p. 203). These examples indicate the importance of specifying the theoretical context within which one intends to develop abstractions that are suited to capture the 'non-chromatic intensity' aspect of colour experiences. Without such a specification, there are no criteria to decide whether 'brightness' is to be conceived as an attribute pertaining, for example, to a colour patch itself, i.e. a local property, or as an attribute pertaining to a colour patch within an entire configuration, i.e. a relational property, or, referred to as 'lightness', as an "attribute of a visual sensation according to which the area in which the visual stimulus is presented appears to emit more or less light" (Wyszecki & Stiles, 1982, p. 487).

While for Evans brightness is the most problematic concept, others consider saturation as the most inappropriate concept of the standard set of alleged basic colour attributes. According to Wyszecki (1986, p. 9-5), "the concepts, terms, and definitions of chroma and saturation are perhaps the most controversial in the literature of colour appearance." Hering (1920, p. 40) rejected the concept of saturation altogether as a mixing-up of perceptual and physical aspects (he preferred the concept of veiling, *"Verhüllung"*, of colour). Stumpf (1917, p. 86) also dismissed 'saturation' as a colour attribute completely. He conceived saturation to be "a cognitive abstraction and a cognitively added relation capturing the approximation of a colour to its ideal". In a similar vein the concept of saturation was rejected by many others, among them Katz, G.E. Müller, and K. Bühler. Hunt (1977), at that time chairman of the CIE Colorimetry Committee, introduced the concept "colourfulness", because judgements of saturation also refer to the brightness and thus do not capture, in certain situations, the qualitative aspect that a hue may be exhibited weakly or strongly.

The issues underlying these controversies are not merely terminological in nature but rather mirror crucial differences in underlying purposes and theoretical perspectives. This, however, is veiled by the fact that these kinds of basic attributes, however they may be defined in detail, roughly seem to describe what appears, within our present-day ordinary way of dealing with colour, as qualitative 'dimensions' of colour. When we are called upon to describe differences in colours in our visual world by abstracting from all other aspects of spatial and temporal context and psychological attitude, and confining our judgement to 'pure colour aspects', it seems to be natural to roughly distinguish variations in the kind of hue - "the main quality factor in colour" (Evans, 1948, p. 118) - in the 'intensity' of the patch and in the amount of its chromatic vividness. Still, this kind of taxonomy is yielded by an abstraction that requires a proper mental attitude and rests itself on conceptions that were shaped by developments of colour technology; sensory qualities do not come with a tag indicating how to slice them in a certain way into 'basic qualities' (cf. Aubert, 1865, p. 186). The specification of basic colour attributes is brought forth, within certain theoretical and practical contexts, by corresponding abstractions, as has repeatedly been emphasised in the literature. Stumpf (1917, p. 8), for instance, insisted that a specification of colour attributes is based on the "ability and the conditions for an isolating abstraction"; and Burnham, Hanes & Bartleson (1963, p. 5), in a report on behalf of the *Inter-Society Color Council*, regarded these "visually abstractable dimensions" as representing "an abstraction from a total visual experience" and emphasised that they "represent a cultural development upon which there is reasonably general agreement." Concepts of basic colour attributes, such as hue, saturation and brightness, are *theoretical terms* that have been developed and abstracted from colour experiences for certain purposes. Though they have become part of our ordinary language they are still artificial abstractions (which, of course, are based on and exploit certain perceptual capacities). For perception theory, however, a proper understanding of colour will most likely be impeded by confusing these theoretical terms with basic structural 'dimensions' of the internal organisation of colour.

Modes of Appearance

The problems caused by the "errors of the application of colorimetric thinking to perception" (Evans, 1974, p. 197) become particularly obvious when reference to so-called modes of appearances is made. Introduced, within the context of perceptual psychology, in Katz's (1911) ground-breaking work, observations on these modes of appearances yielded subtle conceptual distinctions (e.g. Martin, 1922; Evans, 1948, 1974; Beck, 1972) that are of great theoretical interest to perceptual psychology. It is important to note that the corresponding concepts have a purely descriptive status and are themselves in need of an explanation in terms of some abstract principles of the internal coding of colour. In the context of colorimetry, the concept of a 'mode of appearance' turned, however, into a pseudo-explanatory one that was called upon to alleviate the obvious inadequacies of the 'basic attributes' of colorimetry in situations other than small decontextualised colour patches; though in the latter situation these attributes indeed suffice to completely describe the colour appearance, they are all too obviously inadequate for more complex situations. In order to accommodate corresponding observations, it became common in colour science to invoke a 'switch in the mode of appearance' (in such usage the concept of 'mode' wavers in its meaning between denoting, in the sense of Katz, colour appearances, or judgmental modes, or attentional modes). Such a move made it possible to simply by-pass the theoretical problems encountered by declaring that modes of appearance merely modify the 'original colour', which is the colour as produced by the aperture mode. [7] It was Katz himself who prepared the way for this conception because he held the view that the 'same colour' - given in its 'pure form' by the aperture mode - may have different modes of appearance and that its different modes of appearance are all based on the same retinal process (Katz, 1911, p. 38).[8] A lot of controversies were spawned by the question, whether different modes of appearance have to count as different colours or simply as different modes of appearance of the *same* colour. [9]

Within perspectives on colour perception that were determined by neurophysiologically-oriented elementaristic approach to colour as well as by colorimetric purposes, the modes of appearance have an enigmatic and peculiar ad hoc character. According to these elementaristic perspectives, there are some kinds of 'raw colours' or 'original colours' that are directly tied to the receptor excitations elicited by the local incoming light stimulus and that are transformed and modified in subsequent stages of processing in order to fulfil certain requirements, such as sensitivity regulations (or, according to more recent variants, optimal and efficient coding or invariance requirements). In the wake of these approaches it became a matter of course to conceive decontextualised small colour patches (that virtually have no localisation or orientation) - such as the ones underlying CIE colour space - as the building blocks of colour perceptions. Perceptual representations of, say surface colours, are, on this view, built up, by 'secondary' or 'higher' processes, in a locally-atomistic way from these raw colours, and the modes of perceptions are merely modifications of the 'original colours' by context dependent factors. Consequently, the interesting theoretical problems that lie beneath their surface were, within such perspectives, not taken seriously or not even recognised. Ideas from the field of colorimetry, which invested great efforts into developing standard procedures for capturing colour appearances, thus became a major obstacle to approaching issues of colour within perception theory in an appropriate manner.

The Cultural Development of Colour Terms

The process of standardising colour, an issue that is of vital concern for a great variety of practical and industrial purposes and largely divorced from perception theory, has reciprocally influenced our ordinary way of dealing with colour. It is, though, not a singular process in the culturally-driven process of developing abstractions for dealing with perceptual experiences. I will briefly mention a few observations that provide evidence that, from the very beginning of human culture, the building up of a colour terminology has mirrored not only the significance of certain biologically important objects, but, to an increasing extent, the invention and cultural role of coloration techniques and dyeing processes, the cultural context and the degree of linguistic abstraction achieved. My reasons for dealing with these issues are twofold. First, these observations are further evidence - in addition to the fierce controversies within colorimetry about what the 'basic attributes' of colour are - that the alleged basic attributes of hue, saturation, and brightness are abstractions rather than 'natural kinds' of colour experiences. Second, these observations of the cultural development of colour terms exhibit a regularity that seems to me to be of theoretical interest in its own right with respect to the perspective pursued here, namely a shift from 'forms of light' to object properties. This shift is consonant with the idea that the internal concept of 'colour' is not a unitary one but rather figures in the data format of two different representational primitives, and indicates that the way in which we linguistically exploit these primitives has changed.

In our common-sense perceptual taxonomies, our conscious awareness is of objects and their material character, whereas colour appearances only seem to be a kind of medium we are reading through, as it were, in the visual system's attempts to functionally attain the biologically significant object. People at earlier stages of cultural evolution had no grounds for abstracting away from concrete experiences and for assigning names to 'pure sensations'. [10] Colour itself was not the primary distinguishing feature of objects, and for most natural objects the name alone was sufficient to describe the colour. [11] Thus, any vocabulary that referred to the domain of colour was accommodated exactly to the respective demands of daily needs and cultural practices. [12] Along with these needs and practices, the way we talk about colour is continuously changing. From Homer's emphasis on forms of light, such as brightness, lustre, and the changeability of colours [13] to the subsequent and continuing interest in the proper colour of objects and in colour as such, there has been a culturally-shaped progression toward an increasingly abstract colour vocabulary. The cognitive bases for this progression in the linguistic description of colour experiences are cognitive processes of similarity classification and abstractive categorisation. When we talk today about colour we refer to abstracta such as 'red', 'green', 'brown' or 'purple'. Usually we do not understand these terms as referring to a specific external world object, but rather as descriptions of perceptual qualities as such. We have thus abstracted away from any object of perceptual reference and have assigned a meaning to a sensation. [14] Yet, this process of increasing abstraction that we can observe in the development of a colour vocabulary, seems to exhibit an interesting regularity: namely a shift from an emphasis on forms of light, such as brightness, lustre, and the changeability of colours to an emphasis on hue as an object property. [15] [16]The occurrence of such a shift can, in principle, be accommodated in a natural way within the general perspective that I argue for below, namely that the internal concept of 'colour' is not a unitary one but rather figures in the data format of two different representational primitives. The shift from 'forms of light' to object properties indicates that the way in which we linguistically exploit representational capacities of the perceptual system has changed due to cultural and technological factors. Cultural processes have favoured an increasing linguistic apprehension of 'colour' as part of the internal data format of surface representations, while at the same time lessening the importance of 'colour' as part of the internal data format of the transmission medium.

Second Obstacle: Neglect of illumination perception, and the predominance of an adaptational perspective

The neglect of illumination-related issues in perception theory can be traced back to the work of Helmholtz and Hering. Although phenomena such as coloured shadows, transparency and veiling, Meyer's tissue contrast etc. played an important part in their controversies, and although both clearly recognised the challenge that ensued from so-called constancy phenomena, they did not, however, arrive at a proper account for the role of the internal representation of the illumination. In Helmholtz's account, there are some traces of an internal representation of the ambient illumination but he made short work of the illumination by simply deriving it from the entirety of colours in a visual scene and taking the mean of all colours in a visual scene as a kind of measure for a comparison process by which the concept of white is redefined (Helmholtz, 1896).

Theoretical accounts of colour constancy have tended, in line with elementaristic perspectives on colour perception, to treat variations in the ambient illumination as a kind of 'context effect', i.e. as an effect that modifies and distorts the 'true' or 'original' focal colour, which thus has to be internally restored by compensating processes. In other words, the 'primary elements' of colour perception are constituted on the level on which a stable correspondence between local properties of the sensory input and the neural reaction can be observed, and are then further processed and transformed, modified, or supplemented by 'secondary', 'higher order' processes to yield perceptual achievements or appearances. The local connection between these 'original' colours and colour appearances is considered to be the 'normal case' and thus the so-called constancy phenomena are regarded as more surprising and in greater need of explanation than the 'normal case'. Such a view, like corresponding views elsewhere in perception that derive from folk physics apriori kinds of classification of perceptual effects into basic or primary ones, and secondary or contextual ones, again mirrors a measurement-device misconception of perception. In fact, however, it entirely depends on the theory of the representational primitives underlying colour perception which phenomena are to be considered 'basic' and which 'secondary modifications'. [17]

Within the elementaristic perspective on colour, a natural way of dealing with corresponding phenomena has been to treat them under the heading of adaptation. Adaptational perspectives, which were abetted by ideas from neurophysiology, emphasise the role of simple elementary mechanisms that neutralise the effects of changes of the illumination. The most prominent of these is a von Kries-type normalisation of the receptor output by an illumination-dependent factor, which allows any effects of adaptation to be translated back into physics and to be described *as if* only the effective local physical stimulus had changed. Within functionalist perspectives, it had been observed as early as at the beginning of the last century (e.g. Ives, 1912) that von Kries-type multiplicative processes were able to compensate for a large part of the effects of illumination changes. Accordingly, various rescaling schemes have been proposed that normalise the colour signals with respect to the prevailing illumination (e.g. Koffka, 1932). [18]

Due to the great successes of the elementaristic research paradigm, both in revealing the nature of elementary neural coding of colour and in providing colorimetric formulae which allowed the perceived colours to be successfully predicted under a variety of circumstances (e.g. Judd, 1940), the deeper perceptual problems associated with illumination-related phenomena, such as the so-called problem of colour constancy, were consigned to oblivion for the decades to follow. The two authoritative texts in which the then-reigning research perspectives culminated gave colour constancy short shrift: under the heading of chromatic adaptation, they only devoted a few sentences to it (Boynton, 1979, p. 183f.; Wyszecki & Stiles, 1982, p. 440f.).

It is important to be aware of what, in situations of chromatically illuminated objects, the perceptual achievement that needs to be explained actually is. There is no perfect colour constancy, even under favourable natural conditions, in the sense that two locations of the same spectral reflectance have an identical appearance under two different illuminations. What is actually achieved by the visual system is not an illumination-invariant transformation of retinal colour codes nor an estimation of spectral reflectance functions but rather the percept 'colour of an object', which is more stable than could be expected on the basis of the local sensory input alone. In this sense, the percept 'colour of an object' seems to be more strongly tied to the spectral reflectance characteristics of the object than to the wavelength composition of the local sensory input. There is, however, no colour constancy in the strict sense that two locations of the same spectral reflectance 'look the same' in all respects under two different illuminations. One can see the 'same colour' but yet have a different colour experience by seeing it under a different illumination. As Gelb (1929, p. 672) tersely stated: "Given this state of affairs, can one raise the question in the usual sense, why things keep their appearance with respect to colour in spite of changes in the intensity and kind of illumination? Obviously not." The phenomena concerning the interplay of surfaces and illumination in colour perception point to much deeper principles of the visual system than those of some re-normalising of the local colour code (or, as in functionalist-computational approaches, those of an alleged propensity of the visual system to keep its colour equivalence classes congruent with the physical structure of 'reflectances of surfaces').

Because elementaristic perspectives on colour perception are based on a theoretical language that has no room for 'semantic' perceptual units, they have to invoke various case-dependent ad hoc assumptions, referring to spatial or temporal context, or to attitudes of the observer, in order to 'explain', for the phenomenon in question, how the raw colours are transformed. This finally led to a theoretical picture according to which "chromatic adaptation is, in fact, one of the greatest mysteries of colour science today." (Billmeyer & Saltzman, 1981, p. 21)

From their initial conception, such ideas of taking normalising transformations of primary colour signals as a central mechanism subserving colour constancy have been accompanied by corresponding objections emphasising the principle inadequacy of such approaches. For instance Jaensch (1921; Jaensch & Müller, 1920) put forth an ambitious programme that attempted to identify structural similarities between contrast phenomena and constancy phenomena. His and similar attempts have were sharply attacked by several authors, notably Gelb (1929), Kardos (1934) and Koffka (1932). In particular, it was emphasised that one cannot, on the basis of adaptational concepts, arrive at suitable theoretical concepts for dealing with illumination perception. Evans (1974, p. 197) succinctly stated that "one of the major errors of the application of colorimetric thinking to perception is the assumption (usually unconscious) that what is seen must be explicable by a simple combination of a single stimulus and an eye sensitivity modified by colour adaptation."

Earlier writers, such as Gelb or Kardos, were not willing to sacrifice their insights into essential aspects of colour perception for an explanatory scheme that can, in a deflationary way, accommodate almost all kinds of changes of colour appearance by suitable 'colorimetric formulae' of chromatic adaptation (e.g. Judd, 1940). [19]

Kardos (1934, p. 173) recognised how strongly adaptational concepts are tied to elementaristic and locally-atomistic (mis-)conceptions of colour coding; he concluded from his analyses that "the psychophysical processes that result in a perception of an object colour, cannot be understood as a response to the local stimulus by a sense organ that is adapted and re-tuned to some illumination" but rather considered it as an *"immediate reaction"* to a specific input configuration. Gelb (1929, p. 672) insisted "that the problem of colour constancy, rather than being a problem of an alleged discrepancy between 'stimulus' and 'perceived colour', has to do with the general problem of the constitution and structure of our perceptual visual world. The phenomenal segregation into illumination and illuminated object (i.e. the correlate of the percept 'object colour') reveals a propensity of our sensorium and is nothing but the expression of a certain structural form of our perceptual visual world." In the same vein, Cassirer (1929, p. 155) considers the phenomena that can be observed under chromatic illumination not to result from some additional processing, but rather as an expression of the *"very primordial format of organisation"*. Since at that time these writers did not have the conceptual apparatus provided by computational approaches at their disposal, they had to retreat to circumlocutions in order to express their insights into the structural role of colour within perceptual representations. Still these insights were far from being mere speculations, but rather were, even at that time, strongly suggested by the theoretical and empirical evidence available. Yet, they have been almost completely ignored in subsequent approaches. The problem of colour constancy came to be regarded as a problem confined to 'pure' colour perception, where transformations of some 'raw colours' result in a discounting of the illuminant. As a result of this way of idealising away the perception of the illumination, the problem of colour constancy came to be mis-idealised and misrepresented.

Whereas elementaristic approaches to colour perception dispense with the problem of illumination perception by treating it as a problem of context-specific modifications of 'original colours', current functionalist-computational approaches, which attempt to derive structural properties of colour perception from relevant physical constraints of the external world, tend to trivialise it by conflating perceptual and physical categories (cf. Mausfeld, 2002a). Corresponding ideas that the structure of internal colour representations is determined by the computational goal of recovering from the sensory input a function that depends only on the surface reflectance properties of objects – and a related philosophical position, called 'colour physicalism' according to which colours are to be identified with sets of reflectances[20] - express a distal variant of the measurement-device misconception of perception and also reveal again an empiristic preconception of perception. As this way of referring to spectral remission functions illustrates, functionalist-computational approaches to colour perception tend to throw together two different levels of analysis. One level pertains to the question regarding what properties of the environment give rise to perceptually relevant properties of the incoming light array, and a second, completely different problem is to investigate how structural properties of the incoming light array are exploited by the visual system in terms of its primitives.

Third Obstacle: Conflating levels of analysis

In inquiries into the nature of representational primitives, we can, and, taking a specific subsystem of the organism as the unit of analysis, should actually, avoid any notions of the 'proper' object of perception and the 'true' antecedents of the sensory input among the infinite set of potential causal antecedents (though such notions are, of course, an indispensable part of both ordinary and metatheoretical discourse). The same characteristics of a light array reaching the eye can be physically produced in many different ways. The percept as such, say of a cube, does not testify to its own origin; it can equally result from a distal object, from certain properties of the incoming light array, or from a neural stimulation at various levels of the visual system. There is no way to assign, depending on the way they have been physically caused, different degrees of 'reality' to these percepts. [21]

With respect to the percept 'surface under chromatic illumination' the same spatio-temporal light pattern that is caused by a certain interaction of physical surfaces and light sources and that elicits corresponding percepts can be produced by light sources alone (using, for example, a slide or a CRT screen). The visual system cannot distinguish these cases: it simply doesn't know whether the causal chain giving rise to this pattern arises from surfaces and light, or lights alone. A goal of perceptual psychology is to identify the equivalence classes of input patterns that give rise to the same internal representations or percepts and thus to provide an abstract explanatory framework for the structure of perceptual representations. A description of such equivalence classes in the language of physics will very likely lead to very abstract mathematical entities that are quite unnatural from the point of both theoretical physics and folk physics. This again highlights the futility of attempting to provide a description of the equivalence classes of colour codes in terms of their possible physical causes: colours do not constitute a well-formed physical kind.

Because the equivalence classes are 'held together' by the structure of our perceptual system, rather than by the structure of the physical environment itself, any reference to the potential distal causes of the incoming light array is extrinsic to a formal theory of colour perception. Again, no notions of reference to the environment figure in formal theories that provide explanatory frameworks for our understanding of the internal structure of colour. The question of whether colours 'represent' what they normally stem from in our environment is of little relevance to our formal theories of perception, though corresponding considerations are an indispensable part of our *metatheoretical* talk about colours.

The only physics of the external world that figures in a formal theory of visual perception is the physico-geometric properties of the incoming light array. In terms of these properties, we can completely characterise the relation of representational primitives to the sensory input, and thus their 'proximal semantics', as it were, which can extensionally be understood as the equivalence classes of the physical input situations by which these primitives are triggered. The 'proximal semantics' of the perceptual system is, in other words, defined by its relation to the sensory system. [22] Perceptual psychology aims, within the conceptual framework of the natural sciences, to provide, on a suitable level of description, explanatory frameworks for a specific subsystem of the brain. The functioning of these systems is essentially determined by the way physico-geometrical properties of the sensory input are exploited by the perceptual system in terms of its primitives. Questions as to which distal physical situations are the potential causal antecedents of the values of certain sensory codes as well as questions of evolutionary history pertain, aside from heuristic purposes, to different levels of analysis that are extrinsic though they may supplement perception theory proper.

Corresponding methodological principles are routinely employed in other domains of the natural sciences with respect to other 'natural objects', and there is no reason to deviate from them in the case of perceptual systems. They are considered uncontroversial, for instance, in scientific inquiries into the digestion system and the stomach, where no one would maintain that in order to understand its function one has to take into account its evolutionary history, or physical or chemical regularities of food composition in a certain environment. An explanatory account of its function will most likely refer to various types of internal constraints that result from its interplay with other systems, such as the circulatory system or the immune system, and would not change even if the organism lived under circumstances where the necessary nutrients were provided in an entirely artificial way.

With respect to colour, the structure of relevant internal representations cannot simply be revealed by referring to physical properties, such as surface reflectance characteristics, from the outset because there are no such things in the incoming light array. They cannot even be assumed to be necessary causes for the corresponding categories. Internal concepts, such as 'surface colours', are not constituted by the corresponding categories of physics or tied to them e.g. in the sense of the latter being necessary and sufficient conditions for the former. Rather they are constituted not only by regularities of the external physical world but also by biological regularities that are contingent with respect to physics, by internal physical and architectural constraints, and by contingent properties of internal coding, constraints about which nothing much is presently known.

Current functionalist-computational approaches to colour perception tend to substantially (rather then merely heuristically) base their physical descriptions of the sensory *input* on categories of the yet-to-be explained perceptual *output*, such as 'surface', 'shadow', or 'illumination', and to tacitly presuppose the perceptual concepts and categories which they profess to produce as a result of the computational procedures. By conflating different levels of analysis in this way, more specifically by conflating propositions about the physical world as such with those about the world as structured by the yet-to-be-explained perceptual system of an observer, they dodge an essential task of perceptual research, viz. the identification of the internal conceptual structure of perception.

Triggering and Parameter Setting: The Dual Function of Sensory Codes with Respect to Representational Primitives

The elementaristic perspective in colour perception, whose conceptual framework fundamentally rests on the measurement-device misconception of perception and is shaped by concepts from neurophysiology and colorimetry, is obviously ill-equipped to deal in a theoretically fruitful way with the complex role ‘colour’ plays within cognitive architecture. As it has frequently been pointed out in the earlier literature, inquiries into colour perception, if divorced from general inquiries into the structure of representational primitives, will fail to appropriately capture the relevant aspects of this role and almost inevitably result in a distorted theoretical picture. Theoretical frameworks appropriate for colour perception must be general enough to also be appropriate for dealing with the structure of representational primitives.

The theoretical perspective from which I will approach colour perception is basically derived from two kinds of sources that are intimately connected in some of their core ideas. Firstly, an ethological approach, as pioneered - taking the entire organism as the level of analysis - by v. Uexküll, Lorenz and Tinbergen, and couched, with respect to specific subsystems, in computational terms by e.g. Hassenstein and Reichardt (1956), and extended to richer and more complex biological functions by e.g. Wehner, (1987), Marler (1999), or Gallistel (1998). Secondly, by an internalist line of thinking, as described above, which found its most elaborate expression in Chomsky's (e.g. 2000) *internalist* inquiries into the nature of language and mind. A cardinal feature of an ethology-inspired internalist approach, which in its basic conceptions is in line with deep conceptual clarifications of the nature of perception that have been achieved in the history of the field, notably in the seventeenth century[23], is that it focuses attention on the rich internal conceptual structure which the perceptual system is biologically endowed with. In specific domains, such an approach has already yielded intriguing explanatory frameworks of promising range and depth. In perceptual psychology, its basic tenets are receiving support from a wealth of empirical and theoretical evidence that has been marshalled by Gestalt psychology, Michotte's "experimental phenomenology", studies with newborns and young children, and computational analyses: this evidence indicates that the structure of internal coding is built up in terms of a rich set of *representational primitives*. [24]

The Relation between the Sensory Input and the Representational Primitives

The theoretical picture that has emerged from corresponding studies can abstractly be condensed in this way: perception cannot be understood as the 'recovery' of physical world structure from sensory structure by input-based computational processes. Rather, the sensory input serves as a kind of sign for biologically relevant aspects of the external world that elicits internal representations on the basis of given representational primitives. [25] Although the sensory input is a causally necessary requirement for perceptual representations, the perceptual computations triggered are under the control of an internal programme based on a set of representational primitives; they are representation-driven rather than stimulus-driven.

These primitives determine the data format, as it were, of internal coding. Each primitive has its own proprietary types of parameters, relations and transformations that govern its relation to other primitives. The data structure for the internal representational primitive 'surface', for instance, can be expected to include a set of *free parameters*, which refer to attributes such as 'colour', 'stability', 'tenacity', ‘ruggedness’, 'orientation', etc. (again to be understood as *internal*, and not as physical attributes) as well as parameters for ‘ambient illumination’ and ‘local illumination’. Note again that within an ethological and internalist approach the use of the term 'surface representation' serves only as a convenient abbreviation for an element of postulated internal structure (whose nature we presently only poorly understand), whose core properties seem to be describable, at a meta-theoretical level, in terms of perceptual achievements that are related to actual surfaces; it is not, in any meaningful sense, to be understood as a representation *of* physical surfaces, and neither involves any particular ontological commitments about mental entities nor, on this level of analysis, any reference to the external world.

The values of the free parameters, which lie in a specific region of the corresponding parameter space, have to be determined by the sensory input (and are probably modulated by factors such as 'attentional weight'). The sensory codes thus serve a *dual* function: firstly, they provide triggering cues for representational primitives and thus they determine the potential data formats in terms of which input properties are to be exploited. Secondly, they are used by the activated primitives to determine the values of their free parameters. The activation of a representational primitive and the determination of the free parameters have to be dynamically interlocked. On the one hand, values can only be assigned to free parameters once the data format has been determined; on the other hand, the activation of a specific data format requires that the values assigned to the free parameters be in a permissible range and lie in a specific region of the corresponding parameter space (if certain types of parameters belong to more than one representational primitives, their values are very likely constrained differently).

Although the properties and interdependencies of the free parameters of representational primitives have to mirror, with respect to the perceptual system as an *entirety*, biologically-relevant structural properties of the external world, empirical evidence strongly suggests that they are co-determined by internal aspects, such as internal functional constraints or internal architectural constraints, such as legibility requirements at interfaces. The complex and up-to-now poorly understood interdependencies of free parameters, which do not simply mirror external physical regularities, contribute to the fact that representational primitives defy definition in terms of a corresponding physical concept (even in the sense of the latter providing necessary and sufficient conditions for the former); rather, they have their own peculiar and yet-to-be identified relation to the sensory input and may also depend intrinsically on other representational primitives, in a way that cannot simply be derived from considerations of external regularities, however appropriately we have chosen our vocabulary for describing the external world.

Non-Reducible Primitives of the Perceptual System

When dealing with perceptual systems as complex as ours, this general theoretical picture requires, in my view, a refinement by distinguishing in a specific way between a sensory system and a perceptual system. Before I characterise this distinction, I will try to motivate it.

In evolutionary earliest sensory systems, such as those confined to photo-taxis, the function of the sensory input is to control movement of the organisms with respect to external objects, and thus is, in a sense, completely exhausted by the way it interfaces with the motor system. In the course of evolution, sensory systems of increasing complexity have evolved which exploit and integrate different kinds of input properties for the purpose of the same output function, such as prey catching, and, at even higher levels of complexity, exploit the same input property independently for the purposes of several different output functions, such as feeding and spatial orientation. [26] [27]

In even more complex sensory systems that have to simultaneously subserve a great variety of tasks, the outputs of many sub-systems must be integrated into a common representational structure and made available *internally* for purposes of a great variety of higher-order representations, such as those that perceptually exploit the behaviour of con-specifics. Architectural complexity increased further when perceptual systems came to evolve that "are not linked to specific motor outputs but to cognitive systems involving memory, semantics, planning, and communication" (Goodale, 1995, p. 175), in other words, representational systems which provide the means to assign 'meanings' in terms of 'external world' objects and properties. [28]

Along with increasing computational demands on perceptual architecture and various kinds of internal constraints associated with it, a system of internal perceptual representation has emerged (by processes whose nature still escapes elucidation), which extends far beyond physical aspects of the external world. The rich conceptual structure of the perceptual system cannot simply be understood as mirroring physical categories of the external world. Rather, an adequate explanation is tantamount to apprehending the 'internal semantics' of the system. The ‘internal semantics’ of the perceptual and the cognitive system includes, as had already clearly recognised by Cudworth (1731, p. 155), “intelligible ideas of cause, effect, means, end, priority and posteriority, equality and inequality, order and proportion, symmetry and asymmetry, aptitude and ineptitude, sign and thing signified, whole and part” as well as other “ideas of the mind which were not stamped or imprinted upon it from the sensible objects without, and therefore must needs arise from the innate vigor and activity of the mind it self.” Because the complex conceptual structure of the perceptual system cannot be derived or inductively inferred from the structure of the sensory input, it is, I believe necessary to distinguish a sensory system from a perceptual system in inquiries into human perceptual capacities.

In line with empiristic preconceptions about the conceptual structure of the mind, there have been many highly influential attempts to deny or call into question the need for such a distinction. Such conceptions regard it as desirable to explain the properties of a system entirely in terms of observables. This is, first of all, a perplexing postulate, since it is entirely alien to the methodological principles normally employed in the natural sciences, where we impute existence, subject to empirical verification, to whatever increases the explanatory range and depth of frameworks that account for the relevant observations and facts. Still, conceptions that presume that the conceptual structure underlying perception can be derived from ‘sensory information’ prevail, in various guises, in perception theory. According to such preconceptions, sensory concepts are ‘fundamental’ and are given as part of our biological endowment, whereas non-sensory or non-observational concepts have to be defined in terms of sensory concepts or built up from them inductively. It is well known from the history of epistemology that corresponding programmes in epistemology of founding non-observational terms entirely in sensory ones foundered even in their most sophisticated variants. In perception theory, sophisticated research programmes along these lines, such as Marr’s influential approach or Shepard’s ideas about evolutionary internalised regularities, have enriched the structure of the sensory system by a rich set of internal assumptions and heuristics about the physical world or internalised physico-mathematical regularities that cannot by themselves be derived from the sensory input but rather have to be regarded as part of the biological endowment of the system. However, as mentioned above, the conceptual structure underlying human perception extends far beyond concepts that refer to physical properties of the world. Unless one belittles and grossly underestimates the richness of the conceptual structure of our perceptual system, an appropriate explanatory account of it cannot be derived from the conceptual structure of the sensory system, as empiricist theories of the mind purport to be the case.

The sensory system, as understood in the present distinction, deals with the transduction of physical energy into neural codes and their subsequent transformations into codes that are 'readable' by and fulfil the structural and computational needs of the perceptual system; we can refer to these codes as ‘cues’ or ‘signs’. Its internal concepts are definable in the same physico-geometrical language that we use in psychophysics to describe the sensory input, and its operations are purely sensory-based transformations such as filtering and convolutions, calculation of certain derivatives of luminance distributions, gain control operations or any other mathematical operation of the sensory input or of codes obtained from other such operations. [29] Though the conceptual structure of the sensory system can be described in terms of the physico-geometrical language used for a description of the sensory input, we cannot simply give a direct physical explanation of its properties. Rather we need an additional, more abstract level of analysis, often referred to as ‘computational level’. The reason for this is that even the sensory system is representation-driven (with respect to its internal conceptual structure) rather then input-driven, i.e. the sensory system can generate the same information from a variety of physically different input signals and make it accessible in a highly versatile way for a variety of more complex representations.

The sensory system, according to the distinction made here, pre-processes the sensory input – in a way that is dynamically interlocked with the specific requirements of the representational primitives involved - in terms of a rich set of input-based concepts that are tailored for the structural and computational demands of the perceptual system. The perceptual system, on the other hand, contains, as part of our biological endowment, the exceedingly rich perceptual vocabulary in terms of which we perceive the 'external world', such as 'surface', 'physical object', 'intentional object', 'potential actors', 'self', 'other person', or 'event' (with respect to a great variety of different categories and time scales), with their appropriate attributes such as 'colour', 'shape', 'depth', or 'emotional state', and their appropriate relations such as 'causation' or 'intention'. Thus, its representational primitives, which not only pertain to physical and biological aspects but also to mental states of others, cannot be defined in terms of the primitives of the sensory system: The ability to mentally interact with others rests on representational primitives (whose nature is still at the boundary of scientific elucidation) that have their proprietary ways of exploiting the sensory input. It is an essential characteristic of the way these primitives exploit the sensory input that they go 'beyond' those physico-geometrical properties of the sensory input that are exploited by primitives dealing with the physical world; for instance in perceiving mental states of others, they go beyond what may be called *physical surface characteristics* of the situation encountered.

A core phenomenon of perception that is so pervading and fundamental that it is almost overlooked as still being in need of explanation is what is called ‘figure-ground’ segmentation, correctly regarded as a "major obstacle in developing computational theories" by Weisstein & Wong (1987, p. 61). The occurrence and the specific properties of figure-ground segmentations [30] directly mirror the conceptual structure of the perceptual system, and cannot be derived from sensory-based concepts. The phenomenon of figure-ground segmentation is the result of the way representational primitives, notably those dealing with surface interpretations, interact by virtue of their internal structure. Thus, an explanatory account of figure-ground segmentations is tantamount to an explanatory account of the structure and interplay of representational primitives. Already this apparently simple phenomenon shows that the representational primitives of the perceptual system and the concepts expressed by them cannot be understood in the same physico-geometrical language that we use to describe the input nor in the language that we use to describe the functioning of the sensory system. Although they could in principle be described in such a language, understanding them presupposes an understanding of the internal conceptual structure of the entire system under scrutiny, i.e. of the 'internal semantics' of the system. [31]

Whereas the relation between the 'internal concepts' of the sensory system can be described in terms of causation within the language of physics, the internal relations between the representational primitives of the perceptual system require a level of description that, without thereby implying any specific ontological commitments, we can refer to as 'semantic causation' and describe, purely syntactically, by computational processes. The same holds for the physical causation at the interface of the sensory system and the perceptual system; with respect to this 'semantic causation' we speak of the representational primitives of the perceptual system as being triggered by the signs provided by the sensory system. [32] The perceptual system thus comprises the rich perceptual vocabulary in terms of which the signs delivered by the sensory system are exploited. It furthermore provides the computational means to make these perceptual concepts accessible to higher-order cognitive systems, where meanings are assigned in terms of 'external world' properties. There is, from an ethological perspective, no reason to suspect that there is, with respect to the architecture and functioning of the perceptual system, a fundamental difference between perceiving aspects of the physical world and aspects of the mental states of others. In either case, the sensory input serves as a sign for biologically relevant aspects of the external world that elicits internal representations on the basis of given representational primitives.

Competing Conjoint Representations

In sufficiently complex perceptual systems with a high degree of representational versatility the same type of input code can be exploited by several representational primitives of the same type or by different types of representational primitives with overlapping parameter spaces. When different aspects of the visual input are exploited by the *same* type of representational primitives, for example 'surface' representations, we can encounter situations involving competing interlocked parameters, say for size and distance, orientation and form, or motion direction and form (which can phenomenally be mirrored in multi-stable or vague percepts). A change in the value of one type of parameter, say for coding depth, can, even in cases of otherwise identical stimulus conditions, require considerable changes in other types of parameters, say for coding motion direction or 3D-form. The demonstration by Hornbostel (1922) is a particularly striking classical example showing that a change in parameters for motion direction - and a concomitant change in depth parameters - constrains form parameters in a way that is only compatible with non-rigid transformations of form. Similar observations have been pervasively made with respect to other attributes (e.g. Schwartz & Sperling, 1983; Dosher, Sperling & Wurst, 1986; Kersten, Bülthoff, Schwartz & Kurtz, 1992). For instance, motion can co-determine colour in various ways (Hoffman, this volume; Nijhawan, 1997), and Nakayama, Shimojo and Ramachandran (1990, p. 497) observed that "If perceived transparency is triggered, a number of seemingly more elemental perceptual primitives such as colour, contour, and depth can be radically altered." However, we still have only a poor understanding of which types of representational primitives are involved in these situations.

Of particular interest in the present context is a type of architecture, where the *same* input can be exploited by several *different* but interlocked representational primitives and consequently gives rise to multiple simultaneous layers of representations. These types of representations require special mechanisms and computational means to handle the interlocked way in which they exploit the same input, and give rise to exceedingly complex perceptual achievements. We can refer to these types of representations as *conjoint representations* over the same input (cf. Mausfeld, 2002b). The existence of conjoint representations is a pervading property of highly versatile and complex perceptual systems.

Colour perception appears to be a particularly conspicuous case of conjoint representations. Because the same characteristics, with respect to colour or brightness, of a light array reaching the eye can be physically produced in many different ways (e.g. by different combinations of physical surfaces and light sources or, using a slide or a CRT screen, by light sources alone), representational primitives that subserve different distal interpretations, as it were, compete, on the basis of relevant cues, for the same input. This is an issue that I will address in more detail in the next section. Another related example is that brightness gradients can simultaneously give rise to two incompatible percepts, as already observed by Turhan (1937, p. 46), one of a curved surface (as would result from an 'interpretation' of the sensory input in terms of a specific non-homogeneously illuminated surface) and the other of a slanted flat surface (as would result from an 'interpretation' of the same sensory input in terms of a homogeneously illuminated surface). However, the triggering strength of the sensory input does not suffice to tighten an unambiguous 'interpretation' in terms of either of the representational primitives involved. The internal vagueness with respect to the representational primitives involved is, as Turhan noted, perceptually mirrored in a peculiar impression of perceptual vagueness and indeterminacy.

More complex examples of conjoint representations are pretence play, or watching a theatrical performance. In both of these cases two types of representational structures are simultaneously activated on the basis of the same input signals, yielding two layers of competing interpretations. As Michotte (1960/1991, p. 191f.) properly described the perceptual achievement, in the "duplication of space and time that occurs in theatrical representation the space of the scene seems to be the space in which the represented events are actually taking, or have taken, place and yet it is also continuous with the space of the theatre itself. Similarly for time also, instants, intervals, and successions for the spectators belong primarily to the events they are watching, but they are left nevertheless in their own present."

As mentioned, conjoint representations require special computational means to handle the way in which different representational primitives compete for the same output of the sensory system. In line with empirical evidence, we have to assume that the equivalence classes of physical situations or output codes of the sensory system by which representational primitives are triggered yield, in general, smooth and robust triggering characteristics both with respect to the relation of a single representational primitive to its triggering class of inputs as well as with respect to transitions between representational primitives that exploit the same input. [33]

Usually, in a given input situation (which can also include dynamic sequences of inputs), there is some latitude, the extent of which is determined by the structure of the joint parameter spaces involved, as to which representational primitives could be triggered and which values could be assigned to their free parameters; latitude that corresponds to an ambiguity about which of a set of potential external situations could have given rise to the sensory input. In such cases, the visual system often exhibits a preference for some 'default interpretations'. These preferences can be expected to partly mirror different probabilities of external scenes by which a certain sensory input can be caused under 'normal' ecological conditions. However, such ecological probabilities do not solely or even predominantly determine 'default interpretations', as can be illustrated by the case of the Ames room, or by perceived non-rigid transformations of rotating rigid objects, due to “a *coupled* assignment of motion (direction of rotation) and form." (Dosher, Sperling & Wurst, 1986, p. 973) Rather, in cases where different combinations of values can be assigned to the free parameters, internal constraints that result from various kinds of stability requirements are very likely to play a crucial role in singling out 'default interpretations'. Global stability of super-ordinate representations could be maintained, following small variations in the input, by a strategy in which global changes in the representational primitives triggered and in the values of their free parameters are, intuitively speaking, kept to a minimum (particularly at the interfaces of the perceptual system with the motor system and with higher cognitive systems). Such a strategy would protect the system from settling, under 'impoverished' situations, on some definite interpretation that would have to be changed to an entirely different interpretation following a small variation in the input. [34] [35]

The conceptual structure of the perceptual system provides a pillar for the conceptual structure of higher-order cognitive systems. It furthermore has to suit the ‘conceptual structure’ or schemata of the motor system (the sensory system also interfaces, as plenty of evidence suggests, directly with the motor system; this interface is in evolutionary terms an old one). Consequently, the representational primitives of the perceptual system and their internal structure have to ensure an optimal fit of data formats at the corresponding interfaces. As the essential conceptual tie between the sensory system and higher-order cognitive systems, the perceptual system links the signs provided by the sensory system to the conceptual structure of language and of other cognitive systems. Interestingly, but hardly surprisingly, the conceptual structure of the perceptual system seems, in humans, to resemble more the structure of language (more precisely, the structure of the lexicon of I-language) - where "notions like actor, recipient of action, instrument, event, intention, causation and others are pervasive elements of lexical structure, with their specific properties and interrelations" (Chomsky, 2000, p. 62) - than the structure of the sensory system.

The theoretical framework boldly outlined and tentatively explored here, whose overarching methodological elements are taken from ethology and internalist approaches to the study of the mind, is, needless to say, sketchy and in want of precision and specification. However, in comparison to currently prevailing approaches to perception, which predominantly focus on aspects of processing, much has already been gained if one takes seriously the besetting foundational questions that any successful explanatory account of perception eventually has to answer, viz. the questions as to the conceptual structure of the perceptual system and the nature of the representational primitives giving rise to it. With respect to ‘colour’, a great variety of evidence has been accumulated since the beginning of systematic investigations into the nature of colour perception that suggests that 'colour' cannot be considered as a kind of independent or homogeneous attribute but rather serves different roles and obeys different principles in different conceptual substructures of the perceptual system. [36]

In the following section, I will deal with the role of ‘colour’ within the conceptual structure of the perceptual system and, more specifically, address observations that directly suggest that there are (at least) two different types of representational primitives in which 'colour' figures as a free parameter.

'Colour' as two different kinds of free parameters in the structure of representational primitives

The general and abstract theoretical framework boldly outlined above binds together, on the basis of conventional methodological meta-principles pertaining to the study of complex biological systems, a few very general principles of perception that appear to me both well-motivated and empirically well-supported. The theoretical perspective based on these principles is inevitably conjectural and vague, in the light of what is currently understood of the principles underlying perception. While it can, all the same, serve as guiding lines for inquiry and ways of posing questions, it turns into an explanatory framework for a certain domain only after its blanks have been appropriately specified to render possible specific testable predictions. Since colour perception has been predominantly approached from quite different research perspectives, there is not much experimental evidence available that addresses the issues involved directly and with a sufficient grain of resolution. Fortunately, classical works, apart from some isolated cases in more recent years, paid great heed to questions of illumination perception, and consequently provide a wealth of qualitative observations in light of which the proposed framework can be evaluated. In order to facilitate such an evaluation, I will derive from the more general proposal that ‘colour’ figures in different ways in two different representational primitives pertaining to ‘surfaces’ and ‘illumination’ [37,38] some qualitative predictions, which then can be evaluated with respect to the available empirical evidence.

So let us assume a kind of architecture and functioning of the perceptual system along the general lines described in the previous section as a basis. Let us further assume that among the primitives underlying visual perception, there is a class that pertains to perceptual entities, such as ‘surfaces’, that are usually also potential objects of manipulation, and a class that pertains to the medium, as it were, by which these objects can be attained perceptually, notably ‘ambient illumination’. Each of these different classes of primitives can be characterised by its proprietary type of logical structure or data format; thus, each type has its own proprietary types of parameters, relations and transformations that govern its relation to the sensory input as well as to other primitives. It then seems natural to assume that each of these two classes has a free parameter pertaining to ‘colour’. [39] Both representational primitives consequently form a conjoint representation with respect to the free parameters 'colour' (as well as 'brightness'). The corresponding regions in the parameter spaces for 'colour' of these two representational primitives overlap with respect to both the required input from the sensory system and the outputs that feed into a corresponding parameter in super-ordinate representations. The question then arises, how these two different sets of parameters of the same type are interlocked with respect to the common higher-order representation which they subserve and in which they figure.

Without further specification, we can conceive a great variety of potential architectures in which different properties of these two kinds of parameters pertaining to ‘colour’ can be recognised with respect to specific achievements that can greatly vary with the type of architecture assumed. For instance, it is, in principle, conceivable that the difference between these kinds of parameters is not mirrored in any corresponding differences in appearance but that they feed in a phenomenally silent way, as it were, into certain processes that are in the service of specific functional achievements. With this cautionary note in mind, we can still formulate a few qualitative properties, each of which has some plausibility on the basis of the assumptions made. While neither of them can be, in a proper sense, deduced from them, they would, taken together, provide a sufficiently distinctive set of evidence in favour of the proposed framework.

The following (interrelated) qualitative properties, with which I will deal in the sequel, seem to me particularly natural on the basis of the assumptions made.

1. A significant indication for the existence of two different kinds of colour-related parameters involved in situations of perceived surfaces under chromatic illumination would be provided by evidence that the corresponding colour appearances are simultaneously present at the same ‘location’ as distinctive aspects of the percept. Such evidence would gain in weight if it furthermore proved impossible to compensate for phenomenal changes in one of these aspects by changes with respect to the other.

2. The existence of the two different kinds of parameters pertaining to ‘colour’ should also be reflected in corresponding phenomenal differences of ‘colours as such’. More specifically, there should be two phenomenal realms of ‘colour’, each characterised by specific attributes, depending on the primitive in which they figure. The occurrence of such categorical phenomenal differences does not

require that either a surface or an illumination is phenomenally present as a perceptually discernible entity.

3. For functional reasons it is to be expected that, in general, the two kinds of representational primitives involved break down the sensory colour signal and accordingly assign values to their respective ‘colour’ parameter in a smooth way. Any evidence for conditions under which small changes in certain aspects of the sensory input result in abrupt switches of the assignment of the sensory colour signal from one kind of colour parameters to the other, and thus in a corresponding re-organisation of the percept, would provide significant evidence that the sensory colour signal is split up by two categorically different kinds of primitives.

4. The values of the two different kinds of colour-related parameters can be assumed to be subject to different types of internal and external constraints and to exhibit different properties. These differences, conditional upon the type of primitive involved, can be expected to leave their traces in properties of colour codes for various other kinds of achievements. Such evidence would be particularly compelling for seemingly elementary colour codes pertaining, according to the received view, to levels of the sensory system where a distinction into ‘surface’ and ‘illumination’ properties has not yet been established, such as thresholds and other properties of colour and brightness discrimination.

5. The corresponding ‘colour’ parameter of each of the representational primitives involved can be expected to be intrinsically interwoven with other free parameters of the respective primitive. In particular, the attribute ‘colour of a surface’ is not autonomous, as it were, but rather depends on other attributes pertaining to this representational primitive and to its relation to other primitives of the same or of different types.

There are not many experimental studies in colour science that have been specifically designed to address any of these issues. Many other studies, notably those involving centre-surround stimuli, which have been conducted within very different theoretical approaches, sometimes provide indirect and partial evidence bearing on these issues. Since the evaluation of this evidence is difficult and requires considerable further assumptions, I will primarily draw on qualitative studies that bear more directly on these questions. As mentioned above, many of these studies come from a period where the problem of illumination perception and the dependency of ‘colour’ on the entire ‘structural organisation’ of the percept received greater attention than in more recent periods.

Phenomenal Observations on Surfaces under Chromatic Illumination

As to the first type of qualitative properties based on the assumptions made above, it has been regularly reported, particularly in the classical literature, that in certain situations, even as simple as centre-surround configurations, no satisfactory match between two test fields under different context conditions can been achieved by varying the colour codes of the test field. The way to systematically investigate corresponding issues was prepared by Katz, who in his careful phenomenological observations noted that colour appearances under chromatic illumination have a peculiar character of a kind that cannot be encountered under normal illumination. As a consequence, "attempts to establish colour appearances within a field of view under qualitatively normal illumination that in all respects are equal to colour appearances that can be encountered in fields of view under chromatical illumination are prone to fail." (Katz, 1911, p. 274) Boksch (1927, p. 373) and Gelb (1929, p. 613, 626) made precisely the same observations, which Gelb regarded as "intriguing and theoretically important". Recently, corresponding observations have been made by Brainard, Brunt & Speigle (1997, p. 2098). In general, however, the subtle phenomenal differences in colour appearances under chromatic illumination have often escaped appreciation.

Of particular theoretical interest is that small chromatic deviations from a normal illumination are not perceived as chromatic changes in the illumination but rather as a change in an additional quality that cannot specifically be assigned to either surfaces or illumination but rather pertains to the interplay of illumination and surfaces themselves, namely the warm-cold dimension (as to this dimension cf. Koenderink & van Doorn, this volume). [40]

Brainard, Brunt & Speigle (1997, p. 2098), in their matching experiments, also recognised that they were compelled to resort to a different dimension in describing the subtle differences that impeded a satisfactory match between test fields under different illuminations: "...the test surface (seen under a bluish illuminant) has something of a cool cast about it, whereas the match surface (seen under a yellowish illuminant) has a warm cast. To the observer it seems therefore as if the match surface should be adjusted to more bluish. But this adjustment does not change the warmth of the match surface. Rather, it has the effect of changing (say) a warm gray to a warm blue, which then still fails to match the cool gray test surface." We also encountered a similar effect in simple centre-surround configurations, where under certain conditions subjects were not able to completely compensate for the surround-dependent colour appearance at the location of the test spot (Mausfeld, 1998, p. 244).

The problem of descriptively inadequate accounts of the phenomenal interplay of surfaces and chromatic illuminations is aggravated by the impact that the colorimetric tradition has had on our colour vocabulary. The kinds of concepts provided by the colorimetric traditions veil the subtle differences that are crucial here, where in corresponding matching experiments "some difference remains, although our language has no specific words to designate it" (Koffka, 1935, p. 258). The non-matchability of test fields under different chromatic illuminations indicates that different types of colour codes are simultaneously active, between which only a partial trade-off is possible. These classical findings suggested the construction of experiments in which the Grassmann codes of the area surrounding the test field were held constant, but the ‘interpretation’ of the surround colour, as being due to a chromatic illumination or to the surface characteristics of the surround, was varied. Kroh (1921), for instance, observed that the 'hole colour' in a white reduction screen that is illuminated by reddish light exhibits a larger shift toward green than a 'hole colour' in a reduction screen with a reddish surface of the same colour co-ordinates, and that "an infield undergoes a stronger change in appearance under the condition of a chromatic illumination than under the conditions of a chromatic surround of exactly the same retinal colour codes." (Kroh, 1921, p. 181ff.) In an important experimental study using Hering's 'Nüancierungsapparat", Gelb (1932) found that "the colour as such of the surround does not result in a contrast effect" and that two surrounds that yielded exactly the same colour codes had different effects if seen as a chromatically illuminated surround or a surround of a corresponding surface characteristic. He concluded from his experiments that the segmentation of the visual field into surface and illumination characteristics is a primordial act that is due to the "structural form of our perceptual visual world", rather than being the result of contrast-dependent transformations of the retinal colour signal. Such a conjecture about a dual organisation of colour codes, between which no complete trade-off at the location of the test field is possible, is in line with the phenomenal peculiarities that are characteristic for colour appearances under (chromatic) illumination. Among these phenomena, of particular interest is what Helmholtz (1867, p. 407) called seeing two colours *"at the same location* of the visual field one behind the other", and what Bühler (1922) referred to as "locating colours in perceptual space one behind the other". Similar observations have been made by many others (e.g. Fuchs, 1923a, or Brunswik & Kardos, 1929, p. 316, who attributed them to the "dual nature of the underlying psychophysical processes", or Koffka, 1935, p. 261f., who spoke of a "double representation"). [41]

In simple everyday situations of, say a white wall in a room illuminated by a reddish light, we can 'see' both the colour of the object (e.g. 'white' wall) and the colour of the illumination, though there is, as Katz (1911, p. 274) observed, a "curious lability of colours under chromatic illumination." Gelb (1929, p. 678) noted in such situations that "the solidness and tightness of the segmentation of the visual field undergoes a loss, even at a moderately chromatic illumination" and that "the concepts of 'proper' colour of surfaces and 'normal' illumination intimately correspond with each other" (cf. also Kardos, 1929, p. 50).

Activating Illumination-Related Primitives by Simple Centre-Surround Configurations

The observations just mentioned refer to experimental situations in which actual illuminations are used for setting up the physical stimulus configuration. However, it is, as mentioned above, of no relevance, whether the physico-geometrical characteristics of the incoming sensory input that activate an illumination-interpretation within the visual system are physically caused by an actual illumination or by other ways of establishing the relevant characteristics. We can, thus, expect to find other experimental observations in colour science that directly bear on these issues though they were not constructed by using actual illuminations. Particularly certain bi-segmentations of the visual field as instantiated in centre-surround configurations seem to be likely to activate internal mechanisms that have to do with internally handling the interplay of 'surface' and 'illumination' interpretations. [42] Many observations in these situations can be understood in terms of such achievements (cf. Mausfeld & Niederée, 1993). Among these observations are two classical effects, which played a prominent role in the controversy between Helmholtz and Hering, namely the so-called 'tissue contrast' effect (*"Meyersche Florkontrastversuch"*, Helmholtz, 1896, p. 547) and the observation made with a half-mirror by Ragona Scina (*"Spiegelkontrastversuch"*; Helmholtz, 1896, p. 557; cf. Graham & Brown, 1965, p. 462). They appear innocent enough but are actually still in want of a satisfactory explanation. If analysed in terms of the visual system's attempts to pre-process the incoming colour signal in terms of a dual colour code, they can, however, suggest some conjectures about potential mechanisms underlying a laminar segmentation of the sensory signal into a dual colour code, to which I will turn in the subsequent section.

The 'tissue contrast' effect can be described as follows: If a small piece of grey paper, to which we can refer as test spot, is placed on the centre of a large piece of coloured paper and a piece of tissue paper is then placed over these pieces of paper, the test spot has a colour appearance roughly complementary to the colour of the surrounding piece of paper (while an induced colour is absent or much weaker without the tissue paper). Often, as was also noticed by Helmholtz, the complementary colour of the test spot is much more vivid than the weak colour of the surrounding piece of paper; furthermore, the effect is strongest when test spot and surround are of approximately the same luminance; in particular, the effect is much weaker for a white test spot than for a medium grey test spot. The effect disappears if a small piece of paper is placed on top of the tissue paper, even if it is only placed over a small part of the area of the grey patch. [43] The effect is increased if the tissue paper is moved back and forth, which facilitates a spatial segmentation into depth layers. [44] The tissue paper phenomenon behaves as if the chromatic content of the surround is captured by the spatial layer of the tissue and then interpreted as a chromatic illumination.

These different types of empirical observations bear on the qualitative prediction that both kinds of colour-related parameters are simultaneously present phenomenologically, and that it furthermore proves impossible to compensate for phenomenal changes in one kind of parameter by changes in the other kind of parameter. This seems to me to be a particularly revealing class of evidence supporting the idea that there are different representational primitives in which 'colour' figures, and that consequently we cannot deal with ‚colour' as such detached from inquires into the structure of these primitives.

Modes of Appearance Revisited

The second qualitative prediction also directly bears on this issue. The relevant empirical evidence is commonly classified under the heading 'modes of appearances', a concept which I have already mentioned in a previous section. According to this purely descriptive concept, which itself still requires explanation, the appearances of colour phenomenally segregate into mutually (almost) exclusive categories, which gave rise to the conjecture that these categories mirror internal processes or states of essentially different nature. Many subtle observations and conceptual distinctions have been made that centre around the notion of 'modes of appearances'. In the present context, I will only refer to some rather coarse and well-established observations that seem to me of particular relevance for the issues under scrutiny. The most fundamental dichotomy seems to be the distinction between what are called 'aperture colours' or 'film colours', which are obtained under "complete reduction" of the visual field, on the one hand, and 'surface colours' on the other hand. [45] Katz characterised aperture colours as appearing fronto-parallel and having no orientation in space, appearing spatially two-dimensional but still rendering it possible "to visually dive into them to different depths" (Katz, 1911, p. 7). [46] Surface colours, on the other hand, can exhibit any kind of afrontal orientation, as well as granularity of structure and texture. Only surface colours can appear as having a separate "illumination value", as being illuminated. For colours that appear "matterless" or "objectless" "the possibility to segregate an illumination aspect from them is absent." If, however, "they manifest a distinct surface character, the impression of an illumination becomes cogent." (Katz, 1911, p. 374)

Katz (1911, p. 9; see however Martin, 1922, p. 479) was convinced that "between surface colours and aperture colours all kinds of transitions" can be perceived. [47] Wallach (1976, p. 18) regarded "intensity relations" as a main factor driving different modes of appearance, and accordingly held the dichotomy between a "surface mode" and a "luminous mode" to be fundamental. He observed (ibid. p. 8) that continuous transitions between a grey and a luminous appearance exist, which, for instance, can be experimentally produced by using a half-ring as surround for the test field. Under such conditions, Wallach also found situations in which "the ring is simultaneously gray and luminous" and pointed out that "the existence of a luminous gray is of great importance." The phenomenal dissociation of brightness and greyness and the possibility to elicit both at the same time, also suggest that there are different representational primitives in which 'brightness' figures as a parameter. [48]

It is worth noting that, though the concepts ‘surface colour’ and ‘illumination’ are intimately tied together under these accounts, this does not necessitate that the illumination is also phenomenally present as a distinct separate impression. The activation of some mechanism that internally represents the ambient illumination is not necessarily mirrored as an illumination component in the phenomenal impression. [49] Rather it can, without being phenomenally represented, affect the structure of the percept, which is internally yielded by a processing in terms of representational primitives for ‘surface’ and ‘ambient illumination’ or ‘local illumination’. Such a dissociation can regularly be found under many other experimental conditions, such as Adelson’s corrugated plaid configuration, where often a shadow is not perceptually present, or in Todorovic’s version thereof, where an impression of a local illumination is even more lacking[50], but yet the stimulus configuration is presumably internally processed in these terms.

The conception of ‘colour’ as a parameter of the data structure of representational primitives for ‘surfaces’ also gains support from a clinical observation, following certain brain lesions, of a dissociation of perception of the colour of a surface from the perception of the surface itself. Gelb (1920) reported a case where the patient was no longer able to see surface colours, i.e. all colours had the appearance of film colours. They lacked the object colour's property of being dense and opaque and instead looked ethereal and detached from the corresponding objects and their texture; they seem to be floating in front of the objects and looked fronto-parallel. Though the patient did not see the colour as attached to the surfaces of objects, he showed approximate colour constancy. On the other hand, he was no longer able to see a shadow as such, but rather saw it as a dark spot. Though such observations concerning lesions (the minutiae of which are unknown) are notoriously hard to interpret, they support the idea that the concept ‘colour of an object’ requires a separate representational format to be available. It is of particular interest that in this patient the assignment of the sensory colour signal to a ‘surface’-type representational primitive and thus the internal concept of an object colour has not yet been established, but that none the less there is a pre-processing of the sensory signal yielding what Gelb refers to as approximate colour constancy; thus, a sensory process is still active which is suited to the demands of a normally functioning perceptual system. I will deal with corresponding issues in the subsequent section.

Transitions and Switches in the Activation of Different Types of Primitives

There is a dense accumulation of particulate experimental evidence that bears on the third qualitative prediction of abrupt re-organisations of the percept in the sense of a switch between a surface- and an illumination-related appearance following apparently slight changes in the input pattern. Pertinent and compelling evidence can again be found in the classical literature, where Katz, Gelb, Wallach and many others described a plenitude of situations in which "very small changes in external stimulus conditions or in internal modes of perceiving" are accompanied by quite abrupt transitions between - as Gelb (1929, p. 600) put it with respect to colour - internal states that are “of essentially different nature.” Hering's 'stain-shadow' demonstration *(Fleck-Schatten-Versuch)* is a prototypical example of phenomena that demonstrate how certain attributes can modulate the relation between different representational primitives that exploit a given sensory input. In Hering's demonstrations, slight changes in figural characteristics of the incoming light array, namely masking of the penumbra of a shadow by a dark line, are sufficient to induce a switch to a 'surface' representation that completely exhausts the information related to brightness. [51] [52] There is a wealth of other corresponding observations; for more recent instances see, e.g., Adelson (1993), Knill & Kersten (1991), or Buckley, Frisby & Freeman (1994), Bloj, Kersten & Hurlbert (1999).

Different Properties of Different Kinds of ‘Colour’ Parameters

With respect to the fourth type of qualitative prediction made, namely that, conditional upon this categorical distinction, two different kinds of colour-related parameters exhibit different properties that are mirrored in corresponding differences in properties of colour codes for various other kinds of achievements, direct empirical evidence is still meagre and more difficult to evaluate. But there are a few indications in the presumed direction. For instance, Krüger (1925), among others, observed that the differential sensitivity for detecting brightness differences is much less for brightness changes of the illumination than for brightness changes of surfaces. [53] Further important evidence that is likely to bear on corresponding issues comes from an apparently quite different domain of inquiry, namely from qualitative observations of the way ‘colour’ behaves with respect to figure-ground segmentations. It seems natural to expect that the coding properties pertaining to a representational primitive 'ambient illumination' (or, more abstractly, transmission medium) resemble, and are probably related to, coding properties of the 'ground' in figure-ground segmentations. Observations of figure-ground asymmetries in elementary colour properties by, e.g., Rubin (1921), Fuchs (1923a,b) or Wolff (1935), particularly the observations that a fixed area in a stimulus configuration exhibits stronger colour constancy if perceived as figure than if perceived as ground, forcibly indicate that colour properties are conditional upon the representational primitive in which ‘colour’ figures. [54]

Interdependence of Different Types of Parameters

As to the fifth type of qualitative prediction made above, there is a wealth of experimental evidence that the attribute 'colour of a surface' is not autonomous, as it were, but rather intrinsically depends on other attributes as well, and in turn can influence other attributes. As rich and as variegated as corresponding qualitative observations are, it is difficult to derive more specific theoretical constraints from them. They extend from the dependence of colour appearance on various aspects of form, as demonstrated in Fuchs' (1923a,b) pioneering study, to phenomena such as the Munker-White phenomenon, neon-colour spreading, 'colour from motion' (Hoffman, this volume) to the interdependence of colour and aspects of depth and spatial organisation. The fact that the organisation of 'colour' in terms of the internal interplay of surface- and illumination-related aspects is intrinsically tied to the perceptual organisation of space was particularly emphasised by Hering, Bühler, Kardos and Gelb, who provided rich corresponding empirical evidence. Krauss (1928) furthermore observed that rooms perceptually shrivel in depth under intense chromatic illumination. The idea that colour is not an autonomous attribute, as alleged in much of current research, was almost common-place in the classical literature, as expressed, for instance, by Koffka and Harrower (1931, p. 215), who concluded from their extensive studies, that "the psychophysical processes, occurring in acts of perception, instead of being separable into colour-, space- (local sign), and form-processes are processes of field organization; colour, place and form being three interdependent aspects of this general event."

A discussion of interdependencies between 'colour' and other internal attributes in terms of stimulus variables such as form, motion, depth, texture, etc. may lead one erroneously to conceive of these interdependences in terms of physical input aspects rather than in terms of internal attributes. However, among the internal attributes that are part of the structural format of representational primitives for, say, 'surface' can be attributes that do not have a simple physical correlate in the sensory signal, for example attributes that we can circumlocutory describe as 'stability', 'tenacity', 'ruggedness', or as 'ripe', 'juicy', 'dry' etc. [55]

The empirical evidence on which I have drawn so far is taken from quite different domains and refers to different types of findings and data. It constitutes a particularly distinctive basis for evaluating how explanatory frameworks for colour perception fare as explanatory accounts for a significant range of facts. Naturally, in colour science, as well as in perception science in general, there is considerable disagreement about what should be regarded as significant facts to be explained and what should count as an adequate explanation. But however one construes what is to be regarded as the range of significant facts, the facts and observations referred to above can be discerned as belonging to this range of significant facts that have to be explained under any kind of successful explanatory framework. Taken individually, none of them can, as a matter of course, provide compelling evidence in favour of the theoretical assumptions that gave rise to the above qualitative predictions. Taken as a whole, however, these facts and observations fit, or so it appears to me, in an organic way into the general theoretical framework boldly outlined above. They thus give added credence to this theoretical perspective, which, in its basic contentions, rests on well-founded theoretical bases in various domains of scientific inquiry.

The evaluations of empirical findings in this section have centred around the question of the role ‘colour’ plays within the conceptual structure of the perceptual system. While we are still far from formulating appropriate specific conjectures about the structural form and interdependences of representational primitives underlying perception, available evidence suggests that ‘colour’ figures as a free parameter in two different types of representational primitives, which form a conjoint representation with respect to this parameter. Because of this, the corresponding regions in the parameter spaces for 'colour' of these two representational primitives overlap with respect to the required input from the sensory system, and the visual system has to provide computational means to deal with sensory inputs that are compatible with different parameter combinations in this joint region. The question then arises how the codes provided by the sensory system are exploited by the representational primitives under scrutiny, that is, how the sensory input is pre-processed in order to be compatible and fulfil the demands of the representational primitives involved.

Further Qualitative Observations on the Pre-Processing of the Sensory Colour Codes into Two Components

The sensory system has to provide, at its interface with the perceptual system, a set of codes that optimally fulfil the computational and structural demands of the activated representational primitives. With respect to ‘colour’, the sensory system has to pre-process, within its theoretical vocabulary, the retinal colour codes in a way that allows a specification of the corresponding kinds of free parameters. In particular, the sensory system has to pre-process the retinal colour codes such that they can be segregated into two components that provide a basis for a dual colour code. A great variety of relations on and transformations of retinal colour codes have been found that are potential candidates for such purposes and could act as corresponding cues for the perceptual system; also various schemes have been proposed about how these cues can be integrated and used for a segregation into a dual colour code. Among these are averages of the colour codes of the incoming light array, maximum values of certain codes, ratios of colour codes, various rescaling and normalisation schemes, correlations between luminance and chromaticity, or the properties of the covariance matrix of colour codes (cf. Maloney, this volume; Webster, this volume; MacLeod & Golz, this volume). Similar to what has been found by Marr in other contexts, this shows how surprisingly rich and sophisticated the class of sensory concepts is that can be achieved on the basis of sensory-based transformations under suitable assumptions about relevant aspects of the physical world. This class of concepts is greatly enriched if other sensory codes are additionally taken into account that can act as potential cues to the illuminant, particularly ones that capture relevant aspects of the three-dimensional geometry of the scene.

The relations and transformations just mentioned have been pre-dominantly derived from considerations that refer to actual physical surfaces under chromatic illumination. On the basis of the above-mentioned and empirically supported assumption that centre-surround configurations already can partially activate corresponding primitives and thus elicit processes that subserve the establishment of a dual colour coding, further insights can be achieved about factors that determine or modulate this splitting-up of the retinal colour codes. I will use again the 'tissue contrast' to address a qualitative observation that seems to me of relevance in the present context. Note that placing a piece of tissue over the centre-surround configuration changes several aspects of the stimulus situation: for instance, it blurs the contours, introduces a depth segmentation between tissue paper and centre-surround configuration, introduces texture, reduces the contrast between centre and surround and increases the whiteness of the coloured surround. While a change in any of these and other variables can be expected to influence the establishment of a dual colour code, evidence from other observations, made under a variety of conditions, indicates that the effect of what might be described in terms of a homogeneous whitening of the surround [56] particularly facilitates a laminar segmentation of the incoming colour signal into a dual colour code in terms of a 'illumination'-related component and a 'surface'-related component. It appears as if a high component of common whiteness of surround and centre increases the tendency of the visual system to interpret the surround colour as caused by an ambient illumination and thus to correct for this illumination colour at the location of the test spot. [57] This also holds for simple centre-surround configurations which do not elicit some segmentation into depth layers. Helmholtz had already noted that decreasing the saturation of the surround increases the strength of the so-called simultaneous contrast phenomenon, an observation that comports badly with any ideas of mechanisms of laterally induced contrast. Many corresponding observations have been made since, such as the one made by Walls (1960, p. 34), who projected a disc of white light on a screen, which was surrounded by a broad annulus of coloured light from a second projector: "If now a flood of dim light is put over the screen with a third projector and gradually increased in intensity, one finds that the colored annulus is quickly washed out .. but the colored spot is as saturated as ever, Kirschmann's laws to the contrary. Specifically, if the annulus is blue the spot is yellow, and when the white wash has completely desaturated the blue the spot still glows like a sun. The durability of the induced color has to be seen to be believed - the white wash cannot wash *it* out." Wall's conditions were similar to the ones used in producing coloured shadows, where a wash of white light is placed on the entire scene, particularly on the shadowed region with respect to the chromatic illumination.

In the experimental set-ups just mentioned, whitening in the sense of increasing the common whiteness component of infield and surround (or some other descriptively equivalent parameterisation that adequately captures the relevant internal aspects) seems, in the absence of other relevant cues, to facilitate an internal interpretation in terms of a chromatically illuminated scene. This relation may find its counterpart in corresponding phenomenological observations of colours under chromatic illumination. As regularly reported in the literature, a chromatic illumination produces a phenomenal 'whitening' of the surface colours viewed. Thus, a red surface under a reddish illumination appears somehow as if the red has been washed out, less pronounced, as if a part of the redness of the incoming colour signal is ascribed to the illumination and thus not available for an assignment to the colour of the surface. [58]

If centre-surround configurations suffice to (partially) trigger in the perceptual system conjoint representational primitives that internally handle them in terms of a centre surface that is chromatically illuminated by a surround-dependent illumination, whereby the chromaticity of the illumination is determined from the surround colour, it does not come as a surprise then that in many investigations based on such stimulus configurations - from Bühler (1922) to Walraven (1976), Jenness & Shevell (1995), Wesner & Shevell (1992), Schirillo & Shevell (2000), Mausfeld & Andres (2002), and many others - it has been observed that regularities found with centre-surround configurations can be better understood if an interpretation in terms of an illuminated scene is employed. [59] Such an interpretation cannot and does not refer to actual surfaces or illuminations but rather to corresponding internal representations. Evidently, there are infinitely many different potential distal scenes and thus different combinations of surfaces and illuminations or lights alone that may have caused the physico-geometrical proximal pattern of a centre-surround configuration. From a functional point of view, it would not make sense for the visual system to single out any of these potential external world interpretations in a situation that is meagre with respect to the demands of the representational primitives involved. The more surprising it is that the visual system nevertheless exhibits some dispositions to pre-process such configurations as if it would favour a certain type of decomposition of the incoming light pattern in such situations. Thus, it is precisely *because* centre-surround configurations are impoverished with respect to the demands of the representational primitives involved that they can be used to reveal pre-dispositions and 'default assumptions' in splitting-up the retinal colour code into two components.

The 'colour' parameters of the representational primitives involved are intrinsically interwoven with other free parameters of these primitives, as the experimental evidence mentioned above indicates. Because of this, it is highly unlikely that an assignment of values to the respective 'colour' parameters can be made on the basis of relations on or transformations of retinal colour codes alone (as computational schemes based entirely on colour codes presume). Rather, these relations and transformations within the sensory system can only yield some solution space for permissible pairs of values for the free parameters involved. Various other types of sensory codes (for instance ones pertaining to spatial and figural aspects) modulate which pair of values of free parameters is singled out from the solution space. It seems reasonable to conjecture that the sensory transformations of retinal colour codes that give rise to a solutions space for pairs of ‘colour’ parameters are based on procedures that under ‘physically friendly’ conditions exploit structural regularities that different kind of situations have in common and thus sufficiently well approximate a variety of situations in which light and surface colour properties are entangled. These can be as diverse as viewing surfaces under chromatic illumination, viewing surfaces through interposed chromatic filters, light scattering, specular transparency or other situations of additive transparency. [60]

The above observation on the effect of a homogeneous whitening of the surround in centre-surround configurations now suggests that the size of the space of permissible pairs of values for the free parameters involved seems to decrease with an increasing saturation of the surround; it seems to converge on a solution where almost the entire value of a local colour code of the surround is assigned to the ‘surface colour’ parameter, whereas the value of the parameter for the ‘illumination colour’ is assigned a value that corresponds to an internal attribute ‘neutral illumination’.

For spatially inhomogeneous surrounds this effect can better be described in more general terms by referring to first- and second-order statistics of retinal colour codes. Mausfeld and Andres (2002) found evidence that second-order statistics of chromatic codes of the incoming light array co-determine the decompositions of the retinal colour codes into a dual code and differentially modulate the relation of the two kinds of representational primitives involved. Roughly, large variances of colour codes in the surround reduce the solution space to values of ‘illumination colour’ that correspond to a ‘neutral illumination’. Small variances of colour codes, on the other hand, which likely yield larger solution spaces, reveal a predisposition of the perceptual system to assign the space-averaged colour code of the scene to the value of the ‘illumination colour’ parameter. This is in line with corresponding every-day observations of surfaces viewed under chromatic illumination. It is also in line with an experimental observation by Metzger & Zöller (1969), who set up, in a viewing box, a scene entirely from objects of roughly the same chromaticity and not too different in lightness that were separated in depth and neutrally illuminated by a hidden light source. They found that “the colour detaches itself from the objects and seems to fill the room with a chromatic illumination, whereas the objects themselves appear achromatic”, i.e. that the chromaticity of the scene was being predominantly attributed to a corresponding illumination. [61]

A wealth of studies on mechanisms of ‘colour constancy’ has unearthed a rich variety of transformations of retinal colour codes that mirror relevant colour-related ecological constraints and potentially co-determine a segmentation into a dual code. The findings just mentioned provide further constraints on computational procedures by which the sensory system pre-processes the retinal colour code in terms of potential values for a dual colour code. However, as many other factors beyond 'colour' co-determine the solution in a given situation, transformations based on colour codes alone do not suffice, as a rule, to single-out an assignment of parameters but can only yield some solution space of permissible pairs of values. Specific values of pairs of parameters can only be singled out by taking into account other types of codes provided by the sensory system in a given situation. With respect to our cognitive architecture, 'colour' is not an autonomous attribute but rather is determined by the structure of representational primitives in which it figures. This sharply contrasts with ideas based on measurement-device conceptions of perception, which attempt to achieve an understanding of how the visual system disentangles illumination colour and surface colour almost entirely within the domain of colour.

Acknowledgement: I wish to thank Franz Faul and Johannes Andres for valuable comments on an earlier draft of this chapter.

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[1] Corresponding ideas have been highly influential since the beginning of systematic inquiries into the nature of perception. They come in many guises and are rarely spelled out as explicitly as, for instance, by Granit (1955, p.9), who characterised psychophysics as the "systematic investigation of our private measuring instruments with the aid of public measuring instruments."

[2] A similar claim in, say olfactory perception, that the olfactory system is concerned with estimating the atomic structure of molecules would duly be rejected as absurd.

[3] Although I will regularly draw on phenomenological observations that appear to be revealing for the structure of perceptual representations, phenomenological observations as such do not necessarily have a particular relevance for perception theory, nor do they carry a kind of 'epistemological superiority'. Phenomenological observations do not provide a 'direct access' to the nature of representational primitives; they rather result from an interplay of various faculties, including linguistic and interpretative ones. Thus they are, within a naturalistic inquiry into the principles of perception, on a par with many other sources that provide relevant facts and observations.

[4] Regarding levels of analysis that pertain to e.g. evolutionary history or 'proper function' as external to an explanatory account of the nature of perception and as belonging to metatheoretical discourse, does not, of course, amount to denying any dependencies. The question is not, how things are related to each other in reality; perception is related to and dependent on various aspects of reality like phylogenetic development, metabolism, the immune system or the physics of the brain. The question is rather what constitutes an appropriate level of idealisation for successful explanatory frameworks of perception.

[5] Corresponding ideas of regarding hue, saturation, and brightness as the 'natural kinds' of colour appearance, as it were, also found their way into corresponding philosophical inquiries into the nature of colour. For instance, Thompson, Palacios and Varela (1992) base their concept of "phenomenal structure of colour space" on these attributes. On their account, phenomenal colour space is placed at the top of a hierarchy of colour spaces, which are vaguely related to levels of neural organisation. Ironically enough, human phenomenal colour space is identified with CIE-space and the corresponding tristimulus values. These co-ordinates, however, are based on colour matching experiments with respect to small spots of light (aperture colours) and have been chosen from a family of linearly related colour codes that includes those that are commonly interpreted as receptoral colour codes. Thus, at the top of the hierarchy of colour spaces, i.e. phenomenal colour space, we find ourselves back at the level of receptoral colour coding.

[6] For centre-surround situations, Niederée (1998) provided, on the basis of a set of straightforward and empirically innocuous assumptions (if one is willing to accept the topological assumptions which, at least implicitly, underlie almost all models of colour), a rigorous proof that the dimensionality of colour codes must be greater than three. As to the question why colour orthodoxy settled, contrary to what should be obvious from the rich evidence available, on *three* 'basic attributes' of colour, Evans (1974, p. 137) suspected that "only a persistent desire to keep the system three-dimensional (so it can be visualized?) can explain the circumlocutions that have been resorted to, to make it so appear."

[7] An example can be found in Judd (1960, p. 257), who, in his attempts to provide an explanation for certain phenomena, referred to an object mode in addition to mechanisms of chromatic adaptation. It thus was only natural that the reigning orthodoxy in colour science confined itself to studying the aperture mode (e.g. Boynton, 1979, p. 28), while the 'modes of appearance' became the epicylcles of theorising within an adaptational perspective.

[8] Katz' approach - which in this regard follows Helmholtz and Hering - is, as Gelb (1929, p. 656) criticised, “basically rooted in a distinction between 'lower' (so-called retinal based) and 'higher' (modified by experience) visual achievements” and thus rests on an inappropriate “segregation of lower, primary processes and higher accessory processes”.

[9] In line with Katz, Jones (1953), in his report as chairman of the *Committee on Colorimetry of the Optical Society of America* expressed the view that "the mode of appearance does not change colour *per se*." In a similar vein, Krantz, using topological arguments (and specifically making the assumption that the existence of an asymmetric match is stable for small perturbations of colour appearance) concluded that "changes in viewing conditions do not introduce new dimensions, rather, they at most create some new combinations of values (e.g., brown) in a fixed set of dimensions." (Suppes, Krantz, Luce & Tversky, 1989, p. 254) In contrast, Evans called into question the unjustified "*assumption* that these changes must occur in the same perceptual variables that are controlled by an isolated stimulus." (Evans, 1974, p. 137) Previously, Troland, who had chaired a *Committee on Colorimetry* which attempted to set forth a clear terminology in the field of colorimetry, considered the modes of appearance to count as different colours. He argued that "hue, saturation and brilliance do not exhaust all possible attributes of colours, since it is possible for them to vary in dimensions distinct from any of these three." (Troland 1929, I, 254) Because of this, he assumed "seven different modes of colour appearance", which he considered to be "not reducible to physical terms."

[10] As Evans (1974, p.199) noted, “In everyday life the colors of objects are not stable and there is no point in trying to assign an exact color to an object.” Our ability to discriminate colours, which exceed our ability to identify colours by a factor of 1000 to 10000, is apparently primarily exploited by mechanisms that subserve achievements such as surface segmentation rather than being mirrored in corresponding phenomenal categorisations.

[11] As an example from the extensive literature, Allen (1892, p. 254; cf. also Rivers, 1901, p.63) concluded that "abstract colour terms are the names of concretes, whose original signification has been forgotten." (cf. also Marty, 1879; Hochegger, 1884)

[12] For example, as Hochegger (1884, p. 57), Allen (1892, p. 271), or Rivers (1901, p. 63) observed, the ancient languages under scrutiny did not have colour names for flowers.

[13] cf. e.g. Rowe 1974; Maxwell-Stuart, 1981. Hochegger (1884, p. 36) found it "remarkable that etymological investigations on abstract colour names always find the roots in words that mean shiny, glowing, burning, shimmering, dingy, burnt, etc. Even the expressions for colours which seem to be abstract are, in fact, not primordial but rather emerged from paleness, brightness, glossy, matt, dingy etc."

[14] It is an interesting observation in its own right that we are endowed with the cognitive capacity to perceptually and conceptually segregate, in a long cultural and intellectual process, pure sensational qualities and abstractions based on them from the immediate perceptual experiences of the external world (conspicuous examples of the ways in which we extensively take advantage of this capacity are geometry, or music and the theory of harmony).

[15] This can be illustrated by the vocabulary of ancient languages, such as Greek, where aspects of light and shadow and the changeability of the appearance of objects were of much greater importance than object colours in our modern sense of appearances that are correlated with invariant spectral remission properties. For the English language Casson (1997, p. 238) showed that colour terms evolved "as a response to an increasingly complex colour world in the Middle English period (1150-1500)" by a shift from brightness aspects to hue aspects. He pointed out that "the eight Old English terms that evolved into basic color terms were predominantly brightness terms that had minor hue sense (except *red*, which had a dominant hue sense)." (ibid. p. 226)

[16] See, however, van Brakel (2002) for a disagreeing perspective on these matters.

[17] MacLeod (1947) clearly recognised how “misleading” such a separation into primary and secondary determinants is as it serves the purpose of avoiding inquiries into the structure of perceptual representations underlying colour perception; he considered it a futile attempt “to explain the behaviour of organised fields in terms of laws generalised from the behaviour of supposedly unorganized fields”, whereas, in fact, “some degree of field organization” has to be presupposed in order to account for corresponding phenomena.

[18] For recent developments along these lines that also address issues of coding efficiency and constraints derived from the statistics of natural images see Webster, this volume, and MacLeod & Golz, this volume.

[19] Faul (this volume), in a similar context, speaks of the “obvious danger of ending in a ‘ptolemaic theory’ of the visual system that is descriptively satisfying but theoretically unfruitful.”

[20] The assertion that the ‘objective basis’ of ‘colours’ were spectral reflectances or that ‘colours’ were even to be identified with spectral reflectances is anthropocentric and attests to an abiological orientation in face of the available ethological facts (e.g. on colour-coding of different directions with respect to the sun in the celestial navigation of birds, or with respect to the water surface in the directional orientation of fish). Such assertions seem to be based on illegitimately transferring common-sense colour taxonomies and common-sense reasoning about colour to scientific inquiry. Likewise, philosophical attempts to justify the realism or other aspects of common-sense reasoning on colour are of no particular interest and relevance for biological inquiries into the role ‘colours’ play within cognitive architecture.

[21] We can, however, introduce a notion of 'reality' that is not tied to a notion of 'reference to the external world' but refers solely to an internal attribute. This has been emphasised by Michotte, who conceived of "*phenomenal reality*" as a "dimension of our visual experience", which is closely linked with "the potential for being manipulated." (Michotte, 1948/1991, p. 181)

[22] Note that the 'proximal semantics' denotes a feature that is defined purely syntactically; the 'proximal semantics' as well as the structural relations among representational primitives are given by

design and are thus essentially impervious to change by experience. (What is modifiable by experience are the values of certain parameters, the latitude of which is determined in a highly specific way that is proprietary to a structure of perceptual representations.)

[23] Among these seventeenth century achievements (cf. e.g. Yolton 1984; 2000; Wilson, 1990), to which Chomsky (1997) referred to as the first cognitive revolution, the work of Arnauld (1683; see also Nadler, 1989) and Cudworth (1731; see also Passmore, 1951) is of particular relevance for perception theory (cf. Mausfeld, 2002a, Appendix).

[24] Michotte was particularly sensitive to the problem of meaning in perceptual theory, which he regarded as being intrinsic to the structure of primitives that underlie perceptual organisation and that "prefigure" the phenomenal world.

[25] Thus, even 'highly impoverished' sensory inputs can trigger perceptual representations whose 'complexity' far exceeds that of the triggering stimulus and whose relation to the sensory input can be contingent from the point of physics or geometry.

[26] In bees, for instance, colour vision proper and wavelength-dependent behaviour coexist and subserve independent functions (cf. Goldsmith, 1990). The action spectra for wavelength-dependent behaviour underlying bees' celestial orientation and navigation, depend on more than one pigment, without exhibiting metameric classes, whereas trichromatic colour vision is exclusively employed in feeding and recognition of the hive. For a related dissociation of wavelength processing and colour perception proper in the human case, see Heywood, Cowey and Newcombe (1991). Cf. also D’Zmura (this volume).

[27] The corresponding sensory-motor subsystems can be organised, functionally as well as neurally, quite independently (e.g., Ingle, 1983), without resulting, beyond some internal co-ordination, in some kind of common representing structure whose internal function goes beyond those of the single subsystems.

[28] Since the evolution of more complex structures apparently takes, as a matter of speaking, advantage of already existing older ones, it is partly mirrored in the functional and neural organisation of the primate brain. For instance, Goodale & Milner (cf. Goodale, 1995) - elaborating on a distinction proposed earlier by Schneider, and Ungerleider and Mishkin - distinguished a dorsal and a ventral cortical stream which they associated with different transformations on the sensory information, namely transformations that relate it to the entirety of visual information in the case of the ventral stream, and transformation into egocentric frameworks for motorial purposes in the case of the dorsal stream.

[29] The research programme pioneered by Marr has shown how surprisingly rich and sophisticated the class of concepts is that can be achieved on the basis of sensory-based transformations under suitable assumptions about relevant aspects of the physical world.

[30] Figure-ground segmentations can refer to different abstract relations between a medium and a perceptual object that it ‘carries’, such as, in the usual understanding of the concept, to its figural aspects, or, in the perceptually important ‘object’ vs. ‘stuff’ distinction, to its material aspects.

[31] Even extremely empiristic accounts of perception, such as Gibson’s, have to permit a level of description in terms of biological and perceptually *meaningful* concepts, in order to account for even the simplest kinds of observations in perception; in Gibson’s case the need to refer to a given conceptual structure of the perceptual system is camouflaged in his concept of ‘affordances’ (such as ‘obstacle’, ‘terrain’, ‘places to hide’, or ‘manœuvrable objects’); by introducing these non-mental, adaptively significant properties of the physical world, Gibson attempts to externalise meaning, as it were.

[32] The distinction between a sensory system and a perceptual system proposed here is different in character from widely made distinctions between so-called earlier or lower-level systems and higher-level systems. The latter basically correspond to the sensation-perception distinction as used by Spencer, James, Wundt or Helmholtz, which refers to an alleged hierarchy of processing stages within the same vocabulary by which the sensory input is transformed into 'perceptions'. In contrast, the present distinction, which is more in line with corresponding distinctions by Descartes, Arnauld, or

Cudworth (cf. Mausfeld, 2002a, Appendix), conceives of the perceptual system as a structure whose primitives cannot be defined in terms of the primitives of the sensory system.

[33] Since triggering a representational primitive is tantamount to exploiting the sensory input (or the output of the sensory system) in terms of a specific data format with a specific set of free parameters, corresponding 'smoothness' requirements apply, as a rule, to the mappings of physical input features to values of the free parameters.

[34] In input situations whose properties are compatible with various combinations of values of the free parameters (of representational primitives of the same or of different types), transitions between different interpretations often appear to be to some extent receptive to modulations by attentional mechanisms.

[35] Phenomena of multistability seem to be primarily due to properties of processes which exploit the visual system's outputs for the purposes of other cognitive structures (cf. Leopold & Logothetis, 1999).

[36] This likely holds for other attributes based on common-sense taxonomies as well; for instance 'transparency' seems to figure in different ways in different conceptual substructures pertaining to occlusion and containment events, as developmental data indicate (Baillargeon & Wang, 2002).

[37] Even at the risk of being repetitious, I will again recall that within the general approach pursued here terms such as 'surface representation' are not, in any meaningful sense, to be understood as a representation *of* physical surfaces but only serves as a convenient abbreviation for an element of postulated internal structure that is entirely determined syntactically, i.e. by its data structure and the kind of transformations and relations that operate on it.

[38] 'Colour' presumably also figures as a free parameter in a variety of super-ordinate primitives that pertain to more complex biologically relevant aspects of the external world, such as those pertaining to 'dangers', 'edible things' or to 'emotional states of others'.

[39] More precisely, the two different parameters involved can be regarded as pertaining to the same attribute, if they are based on the type of input codes of the sensory system and figure as parameters of the same type in some super-ordinate structures and computations. Again, a label such as 'colour' serves only as a convenient meta-theoretical characterisation of a certain type of parameter.

[40] Corresponding perceptual principles according to which small deviations from a quantitatively specified internal reference system are not simply treated as deviations or noise but rather give rise to a new perceptual quality can be found in various other perceptual domains (for instance, small temporal delays at a single ear between identical auditory patterns are perceived as timbre).

[41] While certain situations for activating representational primitives pertaining to 'surface' and 'illumination' result in percepts of having a surface-related and an illumination-related colour phenomenally present simultaneously, there are also situations that activate two surface representations with their proprietary types of parameters so as to yield the almost paradoxical percept of seeing two surfaces at the same 'location' of the visual field simultaneously. Think, for instance, of looking out of a train window at dusk, and simultaneously seeing a red hat on the hat rack and a green tree at the same location in the window. In experimental settings phenomenal transitions have been found between transparent and opaque representations of surfaces (Faul, 1997) or even conditions under which surfaces are simultaneously opaque and transparent (Cavanagh, 1987).

[42] This has already been emphasised by Bühler (1922, p. 131), who conceived of the phenomenon of simultaneous contrast in such situations as a "degenerate marginal phenomenon" attesting to the visual system's attempt to preserve colours under changes of illumination, and by Kardos (1929, p. 44). Naturally, the relevant representational primitives involved do not unfold to their fully-fledged structure under these conditions, in the sense that an overwhelming part of their free parameters remains undetermined, such as, in the case of surface representations, 'depth', 'orientation', or 'texture'.

[43] These observations cannot, without introducing further ad hoc assumptions, such as presumed suitable non-linearities somewhere in the system, simply be subdued to the idea that effects of the

ambient illumination can be accounted for by adaptational modifications of 'original colours' or primary colour codes. Even Walls (1960, p. 34), who maintained that phenomena such as the ones of Land's two-colour projections can be entirely explained by elementary sensory mechanisms such as "spatial induction", "general and local adaptation", and "colour conversion", seemed to be less confident in the case of the tissue paper contrast: "Tongue in cheek, one tells students that this blurs the contour, and that this facilitates induction across it."

[44] The importance of depth segmentation for a segregation of surface and illumination colour has been emphasised by Hering, and more explicitly by Bühler (1922).

[45] Particularly with respect to the first type, there is considerable variation in the vocabulary found in the literature; Katz spoke of "Flächenfarben", Martin (1922, p. 452) of "film colours".

[46] The isolated colour patches underlying the colorimetric traditions, e.g. those used for the determination of colour matching functions, also belong to the class of aperture colours. With the theoretical framework pursued here, aperture colours correspond to in-between stages of *internal* vagueness - which is not to be confused with perceptual vagueness (there is no perceptual vagueness in these cases) -, where the system has not yet been able to settle on a data structure in terms of the representational primitives involved.

[47] The existence of continuous transitions between surface and aperture colour and the even farther-reaching observation that there are colours of the same kind, as it were, in both classes, i.e. that, e.g. a green light and an olive-green surface exhibit some phenomenological similarity, are themselves of great importance. Though in principle these two 'worlds' of colour appearances could have been phenomenologically completely divorced from each other, the adaptive requirement of colour constancy necessitates the possibility of at least a partial compensation between the two. An important consequence of the requirement of ensuring smooth transitions between conjoint representations is the existence of what is called a *'proximal mode'* in perception (cf. Mausfeld, 2002b). Evidently, once we have attained the ability to exercise a suitable 'mental attitude', we can perceptually detach certain attributes from their 'frame of reference' as given by a specific representational primitive in which these attributes figure. Attributes that figure in both types of conjoined representations involved can, apparently, be dissociated from aspects that are proprietary to each of the representations involved. Thus, the existence of a proximal modes helps to protect the system from adopting a behaviour where small continuous changes in the input result in abrupt changes in internal representations. The small decontextualised colour patches underlying colorimetry are, with respect to the representational primitives involved, a degenerate situation that is closely related to the 'proximal mode'. The percept yielded by the 'proximal mode' is sometimes referred to as the 'local colour quale'. In many situations, one can focus attention on the 'local colour quale' as such, or on colour as a property of surfaces (cf. Landauer & Rodger, 1964; Arend & Goldstein, 1987); for instance, a spot appearing grey when seen in the first mode of attention may appear as a shadowed part of a white object or an illuminated part of a black one in the second mode. Situations like these, in which it is possible to produce, by slight changes in the mode of attention, transitions where the "surface gains in whiteness to the same extent that the illumination looses brightness" are, as Gelb (1929, p. 600) rightly noted, of "particular theoretical importance."

[48] Wallach also ventured some conjectures about the way, the two types of parameters involved compete for the same input signal: "We may consider luminosity as the result of that part of the neural representation of stimulation in a given area which does not participate in a 'surface color process'." An area elicits the appearance of an illuminant or self-luminous object, if the value of the relevant sensory signal that is used to specify a 'brightness' parameter in a surface representation exceeds the permissible range of this parameter. In Wallach's words, if the value of the relevant sensory signal is "insufficient to involve in a color surface process all of the process that represents the stimulation in that area, leaving some of it free to function as a luminous process", this furnishes, according to Wallach (1976, p. 10), the explanation for "when we seem to perceive illumination."

[49] Corresponding assumptions were not only made by, e.g., Katz, Gelb, and Wallach but also underlie interpretations of findings in centre-surround type of situations in terms of functional illumination-related achievements, as regularly made in the literature (e.g. Jenness & Shevell (1995), Schirillo & Shevell, 2000; MacLeod & Golz, this volume).

[50] see Adelson (1999)

[51] This is even the case when the physical construction of the situation - that is light source, shadow-casting object and the process of drawing the boundary - is completely transparent to the subject. The available perceptual and cognitive 'interpretations' are completely overruled by a single geometric characteristic.

[52] Metzger (1932, cf. also Heider, 1933) furthermore observed that if a larger screen is introduced between the light source and the shadow, which is surrounded by a dark line, such that the shadow is itself covered by the larger shadow of the screen, it suddenly lightens up and appears much brighter than the surrounding area (sometimes exhibiting a metallic appearance).

[53] In line with corresponding observations on figure-ground organisation, it might reasonably be conjectured that the parameter values for 'illumination' colours are less fine-grained than values for free parameters for surface colours.

[54] Examples of other corresponding findings, which can only be understood by conceiving of 'colour' as an aspect of the structural form of perception, are that the colour of the afterimage can, for identical sensory inputs, depend on the figure-ground segmentation (Fuchs, 1923, p. 291), or that red regions tend to be seen as figures more than blue regions according to Oyama (1960; Weisstein & Wong, 1987, p. 32).

[55] 'Colour' as part of a representational primitive 'surface' is deeply anchored in the entire structure of this primitive. Accordingly, its phenomenal 'dimensions' will likely mirror these structural interdependencies and linguistically comprise all sorts of aspects such as warm/cold, stirring, calm, fresh, dry, juicy ... etc., which refer, in common-sense terms, both to colour 'as such' and to surface properties, affordances, emotional connotations, etc. Because of this, using Munsell chips in order to attempt to understand the role of colour within the structure of perceptual representations must unavoidably result in a vastly distorted theoretical picture (see Wierzbicka, 1990, p. 119, for an illustrative example that refers to the 'juicy' aspect).

[56] Describing construction variables of such effects in these terms is not meant to imply that these are the relevant internal variables responsible for these effects, because the same situation can be equivalently described in terms of other parameters as well.

[57] As Gelb (1929, p. 627) summarised the corresponding observations, "if one wants to elicit pronounced phenomena of colour constancy, one should not use illumination colours that are too saturated."

[58] For instance, Boksch (1927, p. 369/376) reported from his experiments, "Red and colours in its vicinity were not simply seen as red or reddish. Rather the perceived colour is brightened in a peculiar way, glowing, of a spatial character and most of all diluted with white." Furthermore it loses its surface character and appears "in a peculiar way foggish and dissolved."

[59] This connection is made more explicit in Mausfeld & Niederée (1992), where centre-surround configurations are regarded, in an ethological sense, as 'minimal configuration' or sign stimuli for these functional achievements.

[60] cf. Faul, 1997; D'Zmura, Colantoni, Knoblauch & Laget, 1997; Faul & Ekroll, 2002

[61] This effect is reduced if i) all objects are at the same depth, ii) are of the same form, iii) are not distributed over the entire scene, but rather cluster at some location. A black object or some objects of different chromaticity, particularly if not placed into the centre of the scene, do not exercise a strong influence on the effect. However, if a white object is placed into the scene, the effect vanishes.