to appear in: Jonathan Cohen and Mohan Matthen (eds.). *Color Ontology and Color Science.* Cambridge, Mass.: MIT Press.

Colour within an internalist framework: The role of 'colour' in the structure of the perceptual system

Rainer Mausfeld

Colour is, according to prevailing orthodoxy in perceptual psychology, a kind of autonomous and unitary attribute. It is regarded as unitary or homogeneous by assuming that its core properties do not depend on the type of 'perceptual object' to which it pertains and that 'colour per se' constitutes a natural attribute in the functional architecture of the perceptual system. It is regarded as autonomous by assuming that it can be studied in isolation of other perceptual attributes. These assumptions also provide the pillars for the technical field of colorimetry, and have proved very fruitful for neurophysiological investigations into peripheral colour coding. They also have become, in a technology-driven cultural process of abstraction, part of our common-sense conception of colour. With respect to perception theory, however, both assumptions are grossly inadequate, on both empirical and theoretical grounds. Classical authors, such as David Katz, Karl Bühler, Adhémar Gelb, Ludwig Kardos or Kurt Koffka, were keenly aware of this and insisted that enquiries into colour perception cannot be divorced from general enquiries into the structure of the conceptual forms underlying perception. All the same, the idea of an internal homogeneous and autonomous attribute of 'colour per se', mostly taken not as an empirical hypothesis but as a kind of truism, became a guiding idea in perceptual psychology. Here, it has impeded the identification of relevant theoretical issues and consequently has become detrimental for the development of explanatory frameworks for the role of 'colour' within the structure of our perceptual system.

The concept of 'colour per se' as an abstract attribute that can be dealt with in a decontextualised way has been developed, in the technological context of coloration techniques and dyeing-processes, as the basis for standardisations and norms for capturing colour appearances.[1] The idea of 'colour per se' is, thus, the product of technology-shaped cultural abstractions, including its corollary ideas that colour can be characterised by basic colour attributes,

[1] As Wierzbicka (1996, p.287) correctly observed, albeit within a different theoretical perspective, „'Colour' is not a universal human concept. It can of course be created in all human societies, just as the concepts ‚television', ‚computer', or ‚money' can… In all cultures, people are interested in ‚seeing' and in describing what they see, but they don't necessarily isolate ‚colour' as a separate aspect of their visual experience." See Mausfeld (2003a) for further evidence and corresponding references.

such as hue, saturation and brightness, and that colour appearances can be represented by a three-dimensional colour space.[2] These technology-driven abstractions capture a certain part of our exceedingly complex linguistic usage of colour expressions in everyday language, and have in turn shaped our ordinary conception of colour. However, they do not mirror core properties and principles of the internal organisation of colour in the perceptual system and, in the context of perception theory, have generated all sorts of spurious questions, such as to the types of 'basic colour attributes' or the dimensionality of colour space. I have dealt in detail with these issues and the relevant empirical evidence elsewhere (Mausfeld, 1998, 2003a). Here, it may suffice to point out the gross empirical inadequacy, even in centre-surround-type situations, of the idea that colour appearances can be represented by a three-dimensional colour space.[3] Its inappropriateness should already be evident from many classical experiments and observations, for instance Katz's demonstrations of the (at least) bi-dimensionality of achromatic colours. The assumption of three-dimensionality was experimentally tested and shown to be inappropriate in an experiment by Ekroll et al. (2002).[4] Furthermore, Niederée (this volume) rigorously shows that even in centre-surround configurations the dimensionality of colour codes must be greater than three if one is willing to accept the topological assumptions that, at least implicitly, underlie almost all models of colour coding. This empirical and theoretical evidence against the three-dimensionality of colour already indicates that the traditional concept of colour is flawed in a fundamental way. Although the entire conceptual framework underlying the idea of a homogeneous and autonomous attribute of 'colour per se' has been radically called into questions in the earlier literature, it turned into orthodoxy during the first decades of the last century and, since then, is considered a natural and almost compulsory point of departure for dealing with colour within perception theory.

Why, then, do corresponding conceptions of colour as an autonomous and unitary attribute still pervade perceptual psychology, despite the huge amount of evidence to the contrary? It is, it seems, mainly due to the influence of common-sense conceptions of perception which we illegitimately transfer to scientific enquiry. Of course, all fields of scientific enquiry have, inevitably, to start at their origin from everyday experiences and available common-sense concepts. In the process of their development, however, they have to go beyond common-sense conceptions and develop notions and pursue lines of enquiry that are dictated by the needs of coherence and explanatory width and depth. Perception theory is no exception in this regard. The entire history of the development of the natural sciences, notably physics, is pervaded by a tension between concepts on which successful theories could be based, on the one hand, and deeply entrenched common-sense intuitions and notions about the domains

[2] This remark does not apply, of course, to the Grassmann space obtained from metameric matches, which, however, does not say anything about colour appearances but only represents the equivalence classes on spectral energy distributions yielded by the three types of photoreceptors.

[3] For a discussion of theoretical interpretations of centre-surround configurations see Mausfeld & Niederée (1993).

[4] All three-dimensional models of colour coding imply that in the case of chromatic adaptation the values of two different operations coincide, namely the point of achromatic appearance and the convergence point of lines of the same hue. This implication is gravely false, as Ekroll et al. (2002) have shown.

under scrutiny, on the other hand. Unsurprisingly, a corresponding tension will constitute an incommensurably stronger obstacle with respect to the development of perception theory. In perception theory, it will likely prove to be much more difficult than it was in physics to dispense with common-sense intuitions and to instead follow lines of theorising that are traced out by the development of successful explanatory accounts. Although we are well aware that common-sense intuitions and concepts are inapt guides for the endeavour to achieve, within the framework of the natural sciences, a theoretical understanding of perceptual phenomena, we are held captive by the appearances.[5] Unsurprisingly then, there is hardly any other domain of rational enquiry that is so deeply and almost ineradicably imbued by common-sense intuitions as is perception theory. At the roots of these intuitions is our conviction that perception basically works the way it appears to us. It is, however, an essential part of the functioning of our brain that it does not provide us with mechanisms to observe its own machinery, and this also holds for what may be distinguished as the perceptual system. We therefore can only attempt to better understand its underlying principles by the standard methodological approach of the natural sciences and its characteristic far-reaching abstractions and sharp idealisations. While in other areas of the natural sciences, we are willing to trade common-sense intuitions and notions for whatever increases the explanatory depth and width of our theories, we are prone – in what Chomsky (e.g. 2000, p. 77ff.) has called "methodological dualism"- to pursue a different path with respect to mental phenomena. Here, it is often claimed that there are, beyond the usual criteria for successful theories, privileged categories of evidence for what we are willing to consider as 'psychologically real'. Accordingly, in perception theory, the development of explanatory frameworks is often subjected to the unwarranted demand to conform to certain ordinary intuitions of perception. While both philosophy, notably in the 17th century, and perceptual psychology, notably Gestaltists and ethologists, have achieved important insights that go beyond common-sense intuitions and reveal the deeper issues involved, current thinking in both disciplines is dominated by presuppositions of common-sense ideas of perception. Common-sense conceptions appear to have a particularly unfortunate influence on enquiries into the 'nature of colour', where they have hampered the right questions being asked and have impeded the development of appropriate explanatory frameworks for colour perception. If indeed colour cannot be studied in isolation from the type of 'perceptual object' to which it pertains, theoretical frameworks appropriate for colour perception must be general enough to also be appropriate for dealing with the internal structural form of the 'objects' that constitute our perceptual ontology, as it were. Detached from an appropriate theoretical account of perception in general, questions regarding the 'nature of colour' will inevitably remain at the surface of common-sense intuition. I cannot discuss here the vast amount of empirical evidence in support of the view that enquiries into colour perception cannot be divorced from general enquiries into the structure of the conceptual forms underlying perception .[6] I will therefore confine myself to argue this contention in the abstract. Before I will expound some

[5] Actually, the prevailing conceptions of colour go along with an extremely impoverished and oversimplified account of colour appearances.

[6] see Mausfeld (1998, 2003a) and Mausfeld & Andres (2002) for a more detailed account

reflections on what appears to me a fruitful theoretical perspective for dealing with colour perception, I will briefly, and with an eye on colour aspects, deal with some preconceptions that have been illegitimately transferred to perception theory from common-sense intuitions.

The impact of common-sense intuitions on scientific enquiries into perception

In speaking of common-sense conceptions, I will, in the present context, understand the term in the broadest possible way, namely as the diversity of modes in which we conceive of perceptual phenomena and the process of perception itself in all contexts other than that of the natural sciences. This usage comprises not only those concepts and ways of world-making, that underlie, as part of our biological endowment, our ordinary discourse about the world and our acts of perceiving - sometimes referred to as ‘folk physics’ and ‘folk psychology’, but also derived concepts and notions pertaining to perceptual issues that have been developed for purposes other than those of the natural sciences, whether technological, philosophical or of any other kind.

Common-sense tells us that, by and large, perceiving keeps us in direct contact with the world, that it is the external world we perceive and that we perceive it the way it really is. Common-sense further tells us that it is a kind of integral and even immaterial self that is in direct contact with the world, and no brain, no intermediate substrate and no properties of whatever happens in the body between the sensory stimulation and the percept figure in its ordinary accounts. Common-sense discounts, as part of an essential functional achievement of the brain, all the processes that occur between the distal causes and the percept, and thus is convinced that we are in direct contact with the world. On this account, perception is an entirely conspicuous process. Of course, common-sense is willing to except all sorts of sophistications and, in unusual circumstances, exceptions of this account, but otherwise regards it as a kind of truism.

We can therefore distinguish two different, though not unrelated, ideas that characterise, in various guises, common-sense conceptions of perception. The first idea is that perception basically works the way it phenomenally appears to us and that therefore explanatory useful categorisations of phenomena are immediately suggested to us. The second idea is a realistic conception of perception in the sense of a (culturally refined) naïve realism. Attempts to provide some kind of philosophical justification for the realism underlying common-sense conceptions of perception tend to go along with the idea of ‘colour per se’.[7] I will deal in turn with these two ideas and the intuitions ensuing from them, and briefly point out how they have influenced systematic enquiries of perception.

[7] The idea of ‘colour per se’, however, is not tied to these philosophical positions but also prevails in other philosophical perspectives (e.g. Hardin, 1988).

"Perception basically works the way it appears to us"

There are hardly any other phenomena of nature that appear to us to be so plain, self-evident and intellectually transparent as perception. That we have this impression is itself an essential achievement of the brain, which conveys only the final product, as it were, of the functioning of the perceptual system to our phenomenal experience. It is precisely because the functioning of the perceptual system is entirely impenetrable to our phenomenal experience that we are, in our everyday experience, convinced of the integrity of our mental activity. However, the systems of our mind that are involved in perception exhibit the kind of modular structure that is characteristic for all complex biological systems (e.g. Gerhart & Kirschner, 1997; Hartwell, Hopfield, Leibler & Murray, 1999). In everyday discourse, no need arises to distinguish the contributions of different subsystems of the mind/brain, in particular between a perceptual system and higher-order intellectual and interpretative capacities. One of the core theoretical concepts of perception theory, namely modularity, is therefore entirely alien to common-sense intuitions and their holistic conceptions of mental activity. In our phenomenal experience, the contributions of the different systems involved are inseparably interwoven, and nothing suggests that the apparent complexity of the percept is reducible to simple principles of separate subsystems.

In an everyday context, it is, for instance, perfectly adequate and useful to distinguish normal perceptions from illusionary ones. Transferred, however, to the context of scientific enquiry, such a distinction amounts to conflating the contributions of subsystems that must be distinguished in explanatory accounts. The insight that explanatory accounts of mental achievements necessitate a distinction into different mental faculties or modular subsystems can be traced back to the pre-Socratic philosophers. The Pythagoreans distinguished *aisthêsis* and *nous*, a perceiving and a reflecting faculty – a distinction that was among the pillars on which Plato built his conception of a differentiated soul, and that constituted a core element in Aristotle's functional conception of the faculties of the soul. The distinction between a perceptual system proper and the higher cognitive and interpretative capacities by which its outputs can be put to various uses has become a central theoretical element in systematic enquiries into the nature of perception.[8] All the same, the pre-theoretical notion of a 'perceptual illusion' remains a favourite one in traditional approaches to perception, a fact that indicates how deeply perception theory is still imbued with common-sense intuitions. In a more mature science, the idea of classifying phenomena into pre-theoretically anomalous or surprising ones and 'normal' ones would rightly be regarded as rather odd.

[8] For instance, Arnauld and Nicole stated in their Port-Royal Logic of 1642 "that there can be no illusion or error" in perception, and that "the whole error solely results from our false judgments" (p.75). In the same vein, Kant in his *Anthropologie* (I, §10) remarks: "The senses do not deceive us…because they do not make judgements at all, and that is the reason why the error always is due to the intellect." And similarly Helmholtz (1855, p. 100): "The senses cannot deceive us, they work according to their established immutable laws and cannot do otherwise. It is us who are mistaken in our apprehension of the sensory perception."

There is another pre-theoretical classification of phenomena suggested by common-sense intuitions that is illegitimately transferred to perception theory. If, as we are inclined to believe, perception basically works the way it appears to us, it seems natural to group perceptual phenomena according to characteristic phenomenal attributes that they share. Colour appears to be a natural candidate for grouping perceptual phenomena. Corresponding classifications according to what are considered elementary perceptual attributes underlie almost all traditional accounts in perceptual psychology. They are based on the hope that such phenomena also share distinctive aspects with respect to the functioning of the perceptual system and thus can be subsumed under a common explanatory framework. Classifications in terms of alleged elementary attributes then constitute the starting point for the application of a conception of the 'nature of perception' that has become, implicitly or explicitly, the *Standard Model of Perception* in traditional accounts. The basic form of this model can, following Ulric Neisser's (1976, p. 17) characterisation, can be described as depicted in figure 1.

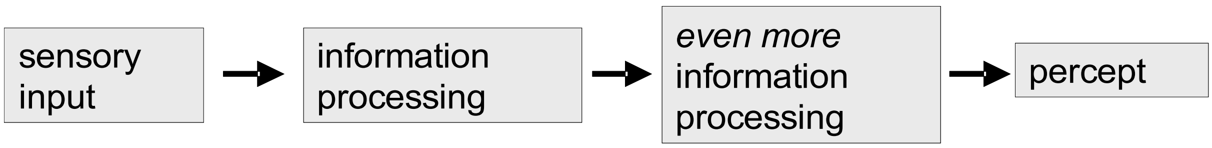

Fig.1: Standard Model of Perception

Applied to colour, a corresponding scheme usually expresses the idea that 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 until the percept is yielded.

There are basically two ways open for interpreting this scheme, both equally fatal. On one interpretation, the arrows indicate, in a loose colloquial manner, some temporal sequence, leaving the kind of relations between the boxes, particularly in the final step, entirely unspecified. The second interpretation understands the arrows as indicating consecutive steps of physically definable transformations by which the output of a previous step is transformed to yield the input for the next transformation, by which finally the percept is yielded. While the first interpretation completely by-passes what can be regarded as the *Fundamental Problem of Perception*, namely to explain how meaningful perceptual categories can arise from a stimulation by physico-geometrical energy patterns, the second interpretation amounts to an alleged solution to this problem that is deeply flawed already on conceptual grounds. This has been clearly recognised by Descartes, and several others before and after him.

"The world, by and large, is as it appears to us"

At the core of common-sense intuitions of perception is what is often referred to as naïve realism, i.e. the idea that the world, as it really is, independently of an observer, is mirrored in perception. Needless to say that perception must structurally mirror or at least not be in conflict with biologically relevant aspects of the external world. This, however, is hardly an insight but simply rephrases, from a functional point of view, the kind of mental phenomena that have been singled out as an object of enquiry. From it, it does not by any means follow that categories or attributes of perception are categories or attributes of the external world: Even if perception would not mirror even in a single case the true manner of being of the external world (whatever that is supposed to be), it still could provide a coupling to biologically relevant structural aspects of it. This has been clearly expressed in Helmholtz' sign theory (and, in different ways, in previous sign conceptions, notably Descartes'[9]).

The explanatory vacuity of the above scheme is, because of our realist convictions about perception, rarely noticed. Our naïve realism with respect to perception - which is, needless to say, culturally shaped in complex ways - seduces us to project the categories of the yet-to-be explained output of the perceptual system back to the external world and to use these projections in turn for a description of the external world and the input.[10] By thus conflating the description of the input with that of the output of the perceptual system, core achievements that actually have to be explained become trivialised. According to traditional accounts, the role of the input is to serve as a kind of data base, from which the distal scene can basically be recovered, yielding the percept. This is, however, as I will point out below, a profound misconception of the role of the sensory input.

It is part of our ordinary realistic conceptions of perception that we take it as a matter of course that the meaning of perceptual concepts is, by and large, fixed by reference to categories of the external world. Common-sense conceptions of perception are therefore intimately tied to an *'externalist semantics'* for perceptual categories and concepts. Because common-sense conceptions have no need to distinguish between the contributions of different subsystems, and thus between the output of a specific subsystem and the potential uses it is put to by other systems, they tend to identify the output of a specific system, viz. the perceptual system, with the results of the functioning of the entire orchestra of mental subsystems, including interpretative ones used for the pragmatics of referring. In ordinary discourse, which has no place for corresponding distinctions, an externalist conception of the meaning of perceptual concepts thus is natural and useful. Scientific enquiries of perception,

[9] see Yolton (1996, ch. 8) for an account of Descartes' sign conception of perception

[10] The predisposition to take perceptual concepts for 'things in the real world' is the distinguishing mark of all of our mental activity. Kant referred to it as the "transcendental illusion". The transcendental illusion is the propensity to "take a subjective necessity of a connection of our concepts…for an objective necessity in the determination of things in themselves" (*Critique of pure reason,* A297/B354). Due to this propensity, whose influence cannot be remedied by intellectual insight into it, we inevitably tend to mistake our own mental categories to hold 'objectively' (cf. Grier, 2001).

however, have to pursue a different path, which is dictated by their specific explanatory purposes. Starting with the fact that the output of the perceptual system, namely meaningful categories, is vastly underdetermined, as it were, by the sensory input, namely physico-geometric energy patterns, the core task of perception theory is to understand the conceptual forms with which our perceptual system is endowed and that constitute the basis for meaningful perceptual categories. For this purpose, it is irrelevant whether the sensory input has been causally generated by a real object, by a picture of this object on a computer screen or by an appropriate stimulation of nerve cells. Fruitful enquiries of perception, notably within ethology and the Gestalt tradition, therefore have pursued an *'internalist semantics'*, according to which the 'meaning' of perceptual categories and concepts is determined by the - yet-to-be-identified - structure of the conceptual forms on which internal information processing is based and by the extremely rich and complex internal interconnections between these conceptual forms. Contrary to our realistic conceptions of perception, meaningful categories are not provided by the external world but by the conceptual endowment of our perceptual system, that is, they are nowhere else than in our head. As Russell (1927, p. 320) succinctly noted: "Whoever accepts the causal theory of perception is compelled to conclude that percepts are in our heads, for they come at the end of a causal chain of physical events leading, spatially, from the object to the brain of the percipient. We cannot suppose that, at the end of this process, the last effect suddenly jumps back to the starting point, like a stretched rope when it snaps." However, current modes of thinking, both in philosophy and psychology, have remained impervious to this incontrovertible argument. This again bears witness to the disastrous influence which naïve realism exerts on our scientific thinking.

Although naïve realism already founders in the face of the most elementary scientific facts, say about the properties of our sense organs, it intellectually expresses some of our deepest convictions about the mental activity of perceiving, namely being in direct touch with a mind-independent world. These convictions are so deeply entrenched in our conception of the world and our interaction with it, that it is hardly surprising that they exercise a continuous impact on perception research, where they often take the form of a measurement-device (mis-)conception of perception (cf. Mausfeld, 2002).

In philosophy, influential strands have attempted to avoid the obvious problems that even sophisticated and culturally shaped variants of naïve realism are facing, while preserving core elements of realist intuitions about perception. There is a great variety of corresponding philosophical attempts, which go under headings such as 'critical realisms', 'scientifically informed realism', and so forth. They generally are accompanied by some kind of metaphysical materialism or physicalism, epistemological reductionism, and the idea that the 'meaning' of a percept is determined by its reference to the external world, and thus is tied to the truth of a corresponding proposition about the world. Accordingly, to understand the 'meaning' of a percept amounts to knowing the conditions under which a corresponding proposition is true. Underlying corresponding philosophical accounts is usually a measurement device (mis-)conception of perception, which takes the form of some kind of local mapping theory of perception. In line with common-sense conceptions that perception is a reconstruction of physical world properties and that each perceptual attribute *is* a representation of a corresponding physical aspect, one can then 'define' an internal attribute in the following way. First, an external attribute is defined by re-mapping aspects of the percept back to the world; from this external attribute then, a 'corresponding' internal attribute is established. According to such conceptions, a percept can essentially be reduced to its 'representational content', which in turn can be identified with a corresponding proposition about an external physical state. Corresponding ideas have fuelled a spectrum of sophisticated philosophical discussions. Whatever their philosophical merits might be, they fortunately do not arise within explanatory frameworks of perception theory (as is particularly evident from ethological frameworks).[11] Notions such as 'truth conditions', 'veridicality', 'reference to the world', and 'perceptual content' belong to the level of persons and do not enter into explanatory accounts of specific subsystems, such as the perceptual systems. They rather describe, mostly in the technical context of philosophical analyses, some aspects of the uses and interpretations to which the outputs of such systems are put by the entire person.

'Colours out there in the world'

Colour has been serving as a paradigmatic study-case for philosophical attempts to justify the realism inherent in common-sense conceptions of perception.[12] This is explicitly expressed by McLaughlin (2003, p. 475): "I persist in the common-sense belief that…colours are really 'out there'. Colours are mind-independent properties of things in the physical world: they are objective properties and our visual experience puts us in touch with them." Corresponding presumptions are the basis of a great variety of philosophical accounts of colour, whether they understand colours as intrinsic properties of external objects (e.g. Byrne & Hilbert, 2003) or as the physical basis for the disposition to look red to a normal observer under normal conditions (McLaughlin, 2003, Cohen, 2003), or argue for a "pluralistic realism" (Matthen, 1999).

These attempts in particular share with common-sense intuitions of perception the externalist idea that colour experiences 'represent' an observer-independent property, i.e. that colours posses 'representational content', which is given by the external properties (single or composed ones) to which they refer (e.g. Matthen, 1988). The primary goal of such 'objectivist' or 'relational' accounts of colour is to establish a correspondence between

---

[11] Although I will touch on a few more general presumptions that certain philosophical approaches share with common-sense intuitions about perception, I do not intent to embark on the issues that are, on a high level of technical sophistication, discussed in the field of philosophy of colour. The reason for this is that corresponding philosophical investigations of colour do not seem to me to have any bearing on perception theory.

[12] 'Colour' as a special domain of philosophical enquiry attains, it appears to me, its particular fascination from tacit common-sense pre-conceptions of perception. The class of attributes of our perceptual experiences is exceedingly rich. Yet, there is no, say, 'philosophy of motion', 'philosophy of texture', or 'philosophy of timbre'.

colours and purely physically definable counterparts.[13] These counterparts can be conceived of as, for instance, the 'categorical bases of the dispositions to elicit colour experience' (e.g. Jackson and Pargetter, 1997; McLaughlin, 2003), or as a single physical property that is 'truly' represented through colour vision (e.g. Byrne & Hilbert, 2003).

With respect to corresponding formulations, such as "red things will be disposed to look red because they have the property of redness" (McLaughlin, 2003, p. 480), Maxwell's (1970, p.33/34) remark seems still in place: "A *redefinition* such as: 'to be red' means to look red under standard lightning conditions, etc., is absurd since it requires that 'red' in the *definiens* have a different meaning from 'red' in the *definiendum* – indeed that it have the primary, occurent meaning. If this defect is repaired and a viable causal or dispositional redefinition of color words is produced so that they may be properly predicated of physical entities, then 'color' in this new sense will no longer be first order properties, but rather, structural ones. Moreover, we will still need color words that have the primary, occurrent sense to refer to the first order properties that are exemplified in our experience. These cannot be eradicated by defining words. I am sorry to take up space with such obvious matters, but sad experience has indicated that it often is necessary."

In the case of physicalist accounts, as proposed by e.g. Byrne and Hilbert (2003), the goal is to show that under certain assumptions representational and phenomenal content correspond to each other (except for certain 'illusions'). However, even if there were such a correspondence, no clear-cut physical notion of 'colour out there in the world' can be justified by it, because, "even if there are colored entities – even colored surfaces as we ordinary conceive them – in the physical environment, we never see them and their being colored plays no role in any process whereby we acquire or confirm knowledge. We thus have no more (perhaps less) reason for believing that there are instances of color in the external world than we do for believing in the existence of disembodied spirits", as Maxwell (1966, p. 170) rightly noticed.[14]

Philosophical attempts to provide a justification for a notion of 'colours out there in the world' essentially amount to normatively and prescriptively introducing a kind of philosophically purified language for a discourse about 'colour out there'. Accordingly, what colour 'really' is, is, what it *should* be, given certain philosophical presumptions about the nature of perception. Prominent among these presumptions is the notion that colour is an autonomous and unitary attribute (an exception is Matthen, 1999), which can be studied as

[13] For comparison, imagine a perceptual system (or an entire organism) that is exactly like ours with two exceptions: It possesses in addition a visual sensitivity for differences in the polarisation of light, and comprises furthermore the basic perceptual attribute 'teavy' (to borrow Carnap's famous term). Assume further that this attribute 'teavy' and its qualitative and quantitative instantiations have as triggering conditions equivalence classes (analogous to metameric classes) of the specific polarisation effects of certain types of material, say soil and desert sand (e.g. Chen & Rao, 1968). Although the perceptual material quality 'teavy' has a physical basis, it would hardly be of any scientific avail to regard 'teaviness' as an aspect of the external world.

[14] cf. also Descartes' remark (*Principles* , I, 70) that, in the context of naturalistic enquiry, "we cannot find an intelligible resemblance between the colour which we suppose to be in objects and that which we experience in our sensation."

detached from general enquiries into the conceptual bases of our perceptual system. In the context of perception theory, however, no physicalist concept of 'colour out there' is required, and no issue of subjectivity or objectivity of colours arises.[15] In fact, corresponding notions would, except for meta-theoretical discourse, not only be unmotivated but also express an anthropocentric and anti-biological attitude.

'Colour' as part of the format of different conceptual forms of the perceptual system

Prevailing accounts of colour in perceptual psychology and in colour science have been almost entirely concerned with sensory-based processes and transformations (see Fig.1). Underlying these accounts, typically, is the concept of 'colour per se' as a homogeneous and autonomous attribute and a measurement-device (mis-)conception of perception. While corresponding conceptions are useful for colorimetrical and for certain neurophysiological purposes, they have made the field of colour science rather sterile with respect to the explanatory goals of perception theory. Overwhelming empirical evidence indicates that the notion of a homogeneous and autonomous 'colour per se' is of no explanatory avail for perception theory because the "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." (Koffka & Harrower, 1931, p. 215) Colour therefore cannot be studied as detached from enquiries into the "processes of field organization" and the structure of the conceptual forms in which it figures as an attribute.

The preoccupation of traditional approaches with aspects of processing has been at the expense of enquiries into the structural format of the perceptual 'data types', as it were, on which computational processes by definition have to be based. Rather, these data types are tacitly borrowed from common-sense conceptions by using the yet-to-be explained *output categories* of the visual system, such as 'surface', 'shadow', or 'illumination', for a physical description of the input. By conflating this way perceptual and physical categories, one of the core problems of perception theory becomes trivialised, namely the identification of the conceptual forms with which our perceptual system is biologically endowed and which sharply constrain the perceptual achievements within the class of achievements that are logically compatible with a given type of sensory input. In contrast, orthodox conceptions and approaches attempt to build-up from the sensory input – on the basis of thin sets of quite elementary perceptual primitives – the complex categories and concepts that characterise the output of the perceptual system. Only by illegitimately transferring common-sense intuition to perception theory do such conceptions gain some apparent plausibility. However, perception theory is not constrained to preserve our pre-theoretical intuitions about perception. In

[15] Also, detached from specific domains of enquiry, no issues of *'what colours really are'* arise. In science, we consider as real whatever figures in our currently best explanatory theories about a range of phenomena of the natural world. In this sense, we can regard as real an attribute 'colour' that figures in an explanatory framework for core principles of the perceptual system, whatever the specific properties of this internal attribute will turn out to be. Beyond that no issues of 'realness' arise.

developing explanatory frameworks for perception, we have to be willing to jettison ordinary intuitions about perception whenever doing so serves our explanatory needs, and to divest theoretical notions of the distorting residues of common-sense intuitions.[16]

Outline of the logical structure of the perceptual system

Recent decades have brought forth, for the first time in the long history of perception theory, a convergence of quite different fields of enquiry - namely ethology and comparative research, perceptual psychology, and investigations of the perceptual capacities of newborns and very young children - on the contours of a theoretical framework about what appears to be basic principles of perception. The core ideas of this framework have a long history in the *philosophia naturalis* (for some historical aspects, see Mausfeld, 2002, Appendix). They were (partly) taken up by Helmholtz in his sign-theory of perception and became the fundamental basis for Gestalt psychology and ethology. Already at the beginning of the last century the empirical and theoretical evidence in support of corresponding ideas was enormously rich. But only after advances in the computational sciences provided a new conceptual apparatus, could these ideas be taken up and further explored in a fruitful manner.

Within computational approaches it is patent that all computational processes require the specification of the data format on which they are based. Though prevailing approaches, in line with empiricist conceptions of the mind, exhibit a preference for data formats that can be defined in terms of elementary sensory aspects, pervading evidence has been accumulated, notably in the Gestaltist and ethological tradition, that our perceptual system is biologically endowed with a rich set of conceptual forms. Hence, the core task of perception theory is to identify the structure of these conceptual forms and to better understand how these conceptual forms can combine to produce the kinds of complex perceptual concepts that characterise the output of the perceptual system.

The theoretical picture that is emerging from corresponding enquiries is still very skeletal and inevitably has to be based on considerable theoretical speculation. But even in its currently still rudimentary form, it has already yielded intriguing results with respect to a range of significant phenomena and has suggested novel and fruitful questions about the internal architecture of perception. Furthermore, it is consonant with well-supported broader meta-theoretical perspectives on the nature of mental phenomena (see e.g. Strawson, 2003; Hinzen, 2006). But our confidence in this theoretical picture is, as always in the natural sciences, predominantly due to the fact that it is the result of a theoretical convergence of quite different disciplines.

In its more general aspects it is rarely spelled out explicitly and therefore has to be extracted and abstracted from the relevant literature. Before putting colour into the context of this emerging theoretical picture of the basic principles of perception, I will briefly describe its skeleton in an unavoidably oversimplified way. I have outlined the general logical structure of

[16] as Chomsky (e.g. 2000) has convincingly argued for in the context of linguistic enquiries

the perceptual system on which different disciplines increasingly seem to converge in more detail in Mausfeld (in press b).

At the core of this theoretical picture is the idea that, in more complex organisms, the sensory input serves as a kind of sign for the activation of biologically given conceptual forms, which determine the data format of the computational processes involved. Conceptual forms can be regarded as semantic atoms of the internal semantics of perception, as providing the core semantics of minimal meaning-bearing elements. The conceptual forms, say for ‘surface’, ‘food’, ‘enemy’, or ‘tool’, cannot be reduced to or inductively derived from the sensory input but are part of the specific biological endowment of the organism under scrutiny.[17] In order to account for the relation between the sensory input and the irreducible and complex perceptual concepts that constitute the output of the perceptual system, a distinction between a *Sensory System* and a *Perceptual System* suggests itself (needless to say, as an idealisation).[18] We can categorise as *Sensory System* those computational processes that are closely tied to the physico-geometric data format by which we describe the sensory input. The *Sensory System* thus 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’. The *Sensory System* pre-processes the sensory input – in a way that is dynamically interlocked with the specific requirements of the *Perceptual System* - in terms of a rich set of essentially input-based concepts that are tailored to the structural and computational demands of the *Perceptual System*. The *Perceptual System*, on the other hand, can be conceived as a self-contained system of perceptual knowledge, which is coded in the structure of its conceptual forms. It contains, as part of our biological endowment, the exceedingly rich set of complex conceptual forms in terms of which we perceive the ‘external world’, such as ‘surface’, ‘physical object’, ‘intentional object’, ‘event’, ‘potential actor’, ‘self’, ‘other person’, or ‘event’, with their associated attributes such as ‘colour’, ‘shape’, ‘depth’, or ‘emotional state’, and their appropriate relations such as ‘causation’ or ‘intention’.[19] The *Perceptual System* therefore comprises the rich perceptual vocabulary in terms of which the signs delivered by the *Sensory System* are exploited, and provides the computational means to make its perceptual concepts accessible to higher-order cognitive systems. The sensory codes serve a dual function. They activate appropriate conceptual forms and thus determine the potential data formats in terms of which input properties are to be exploited. Furthermore, they assign concrete values to the free parameters of the activated forms. The conceptual forms that are yielded, in a given input situation, as outputs of the *Perceptual System* are *triggered* by the

[17] It is important to be aware that these linguistic appellations of the conceptual forms of the *Perceptual System* are only makeshift descriptions of non-linguistic entities (which are, of course, further shaped by the properties of subsequent linguistic and interpretative systems).

[18] I will keep the term ‘perceptual system’ for loosely referring to the entire modular system of perception, which includes the *Sensory System* as well as the *Perceptual System* as characterised here.

[19] According to the architectural conception proposed here, core aspects of most types of build-in ‘knowledge’ as assigned to “core knowledge systems” by Spelke (2000) or to “conceptual-intentional systems” in the minimalist program of linguistics have to be imputed to the *Perceptual System* already.

codes of the *Sensory System*, rather than being computed or inductively inferred from them. We might loosely think of the triggering functions as an interface function that takes specific sensory codes as an argument and calls conceptual forms. The triggering function renders, in principle, the relation between the sensory input and the conceptual forms epistemologically arbitrary.

The abstract functional architecture of perception as suggested by the current convergence of different disciplines can be schematically summarised as depicted in figure 2.

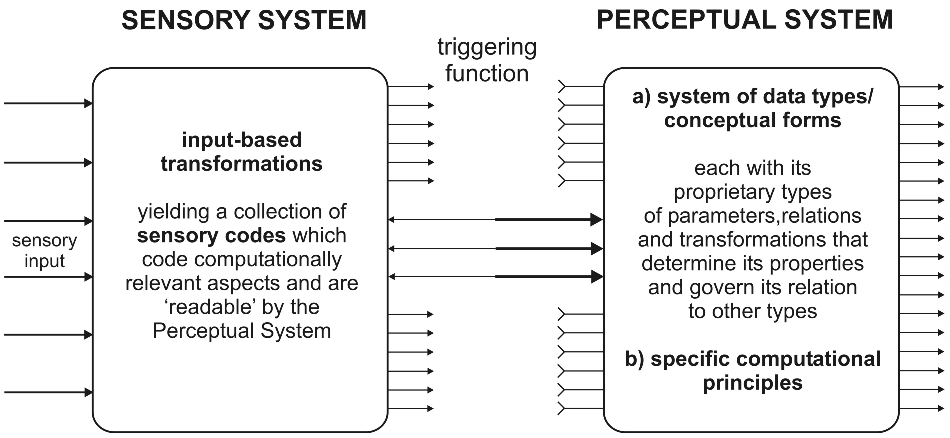

Fig. 2: Basic structural form of the functional architecture of the perceptual system

We can think of the conceptual forms of the *Perceptual System* as abstract structures, each of which has its own proprietary types of parameters, relations and transformations that govern its relation to other conceptual forms and to sensory codes.[20] By means of their relational parameters, conceptual forms build systematically connected packages. The *Perceptual System* generates, at its interface to higher-order interpretative systems, packages of activated conceptual forms that consist of legible instructions for these subsequent systems. The values of the free variables of a conceptual form in general will not be – and, for subsequent computational processes, need not be - exhaustively specified by the activating input. The examples in fig. 2 refer to two types of conceptual forms that are of fundamental importance for colour perception, namely types for 'surfaces' and types for 'ambient illumination'. Empirical evidence suggests that the *Perceptual System* routinely operates semantically with underdetermined conceptual forms (a structural feature that appears to extend to subsequent systems). Accordingly, the output of the *Perceptual System*, at its interfaces to subsequent systems by which meanings are assigned in terms of 'external world' properties, thus needs not to be semantically determinate or unique but only 'good enough' for the semantic needs of the subsequent systems. Underspecification of conceptual forms greatly enhancing the

[20] In philosophical discourse, corresponding conceptions of concepts are sometimes referred to as Cartesian conceptions (e.g. Fodor, 2004). For Descartes, 'ideas' are nothing but forms (as expressed in his *Meditations* in the reply to the 4th set of objections: "ideæ sint formæ quædam"). See Yolton (1984) for Descartes' and Arnauld's conceptions of 'idea'.

compositional versatility of the *Perceptual System*. Furthermore, by postponing disambiguation to higher-order interpretative systems, the *Perceptual System* can increase its global stability with respect to the superordinate 'interpretations' provided at its interfaces to subsequent systems. This protects the system from settling, under insufficient or 'impoverished' input situations, on some definite 'interpretation' that would have to be changed to an entirely different 'interpretation' following a small variation in the input.[21]

The structure of the conceptual forms is only partly visible at the surface of the phenomenal percept. In particular, we do not notice in our phenomenal experience that the conceptual forms involved are underspecified. Rather, the systems that use the outputs of the *Perceptual System* for constructing the phenomenal percept must be furnished with specific computational means to completely specify its phenomenal appearance at each moment.

From an evolutionary point of view, it is usually taken to be a matter of course that the elements of the *Perceptual System* have their specific conceptual and computational structure because they are used to tie the organism to its environment. Conceptual forms by themselves, however, do not refer to the physical world. Rather, their relation is only to other conceptual forms. Their specific form is evolutionarily shaped by the requirement to be functionally adequate, in the sense that they have to fit into the entire perceptual architecture including its interfaces with the *Sensory System*, the motor system and higher-order systems. Furthermore, their form is co-determined by physical and architectural constraints[22] as well as by contingent aspects in the course of the evolutionary development of the brain. Because of this, conceptual forms have their own properties, which can be rather surprising when viewed exclusively from the perspective of an adaptive coupling to the external world. Nevertheless the most complex perceptual achievements - for instance seeing invisible properties of objects (e.g. pertaining to material qualities), intentional properties of objects (e.g. tools), or mental states of others - were made possible only by decoupling the output of the *Perceptual System* from the given sensory input information and by furnishing the *Perceptual System* with perceptual knowledge, coded in its conceptual forms, which is not derivable from the sensory input or from general sensory-based computations.

Evolutionary observations suggest that the emergence of abstract conceptual forms in the functional architecture of the (evolutionary younger) *Perceptual System* is the result of an increasing modular differentiation of the underlying neural substrate. Modularity is generally regarded as the basis of the evolvability of biological systems.[23] In the evolution of complex computational systems, an increasing amount of modularity increases the computational need to integrate the outputs of a great variety of sub-systems into a common conceptual structure, which has to be on a higher level of abstraction than each of the subsystems that feed into it. In this sense, modularity drives abstraction. The conceptual forms of the *Perceptual System*

[21] see Mausfeld (2003b, p. 51ff.) for a discussion of some of the empirical evidence with respect to colour.

[22] for introductionary expositions, from different perspectives, see Stewart (1998), and Carroll (2005)

[23] see e.g. Kirschner & Gerhart (1998); Kitano (2004), Wagner, Mezey, & Calabretta (2005)

can be regarded as the result of corresponding processes of abstraction in the evolution of the brain.[24]

These few remarks may suffice in the present context to convey, on a highly abstract level, some core aspects of the theoretical picture that is currently being achieved in the convergence of ethological, developmental and psychological studies of perception. This conception of perception can, in its basic spirit, be regarded as a fusion of ethological and computational ideas. How radically this conception of perception deviates from common-sense intuitions becomes apparent when one realises that according to it, there is no difference of principle between, say, the perception of colours and the perception of mental states of others; in both cases the sensory input serves as a sign to trigger certain conceptual forms, in which 'colour' and 'mental states of others', respectively, figure as internal attributes.

The non-homogeneity and non-autonomy of colour

Rich evidence of very different types is available in support of the view that 'colour' is not a unitary attribute. Rather, 'colour'-type parameters figure, with different properties, in different conceptual forms and computational subsystems.[25] This evidence ranges from comparative studies (e.g. Santos, Hauser & Spelke, 2001), developmental findings (e.g. Leslie et al., 1998) and clinical observations (e.g. Gelb, 1920; Stoerig, 1998) to experimental findings in perceptual psychology. In Mausfeld (2003a) I deal in greater detail with the empirical evidence that indicates that 'colour'-type parameters figure, with different structural properties, in conceptual forms for 'surfaces' and for 'ambient illumination', yielding a kind of dual coding of colour with intricate interactions and transitions. Here, I will deal with different structural properties (in particular with respect to interrelations with 'space' and 'ambient illumination') of 'colour'-type parameters in different types and instances of 'surfaces'. The natural starting point for this is Katz' distinction of different 'modes colour appearance'. I will briefly discuss this distinction before I turn to the problem of the perception of 'material qualities', which perceptual psychology has, for obvious reasons, notorious difficulties dealing with.

Katz (1911) distinguished, on the basis of phenomenological observations, several types of 'colour', and descriptively classified them into what he called "modes of appearance". Among the ways in which colours appear in space, he in particular distinguished 'aperture colours' from 'surface colours'. Aperture colours have no orientation in space and always appear fronto-parallel. Furthermore they appear spatially two-dimensional and as having no

[24] For some considerations as to the potential evolutionary emergence and the 'biological realness' of abstract conceptual forms, see Mausfeld (in press b).

[25] Linguistic evidence also appears to provide some indirect support for how intimately 'colour' is interwoven with the kind of 'perceptual object' to which it pertains. Interestingly, 'colour'-type attributes also figure with different structural and semantic properties in different items of the I-lexicon (Chomsky, 2000, pp. 35ff., 125ff.). For this and other reasons, it seems to be an intriguing possibility that, from an evolutionary perspective, the conceptual forms of the perceptual system provided the seeds for the development of the items of an I-lexicon (and of the conceptual-intentional system as conceived in the minimalist program).

determinable distance but still render it possible “to visually dive into them to different depths.” Surface colours, on the other hand, can have any kind of afrontal orientation and can exhibit a granularity of structure and texture. Only surface colours can appear to have a separate “illumination value”, i.e. as being illuminated. The guiding idea behind this classification is that the appearances of colour phenomenally segregate into mutually exclusive categories because they mirror internal processes or states of “essentially different nature”. In the wake of Katz’ subtle phenomenological observations, which instigated a wealth of further phenomenological explorations (e.g. Martin, 1922), controversies arose about whether the different modes indeed mirror internal states of essentially different nature or whether they are merely due to the influences of a ‘modifying context’ on the ‘raw original colours’. The question of whether the modes of appearance are different ‘colours per se‘ or the same ‘colours per se‘, which are merely modified by ‘context effects’, is, in nuce, the question of whether colour is or is not a unitary concept with homogeneous coding properties. This question has been intensely debated in the older literature. From the perspective of the colorimetric paradigm, “the mode of appearance does not change colour *per se.* … The modes of appearance are simply the various kinds of context or setting in which color is perceived.“ (Jones, 1953) This has been the prevailing view in perceptual psychology since then. The underlying conception of a ‘raw colour’, ‘original colour’, or ‘colour per se’, which can be indexed by contextual situations to yield colours of transparent, voluminous, glowing, lustrous (and so forth) appearance, has veiled the important theoretical issues involved and brought forth a deeply flawed theoretical picture of colour perception. This conception in particular has concealed the intricate way in which ‘colour’-type parameters are interwoven with other internal attributes within the same conceptual form and other conceptual forms. Among those, ‘space’ (which itself is not a homogeneous concept but comprises a variety of conceptual forms pertaining to spatial aspects) stands out as of unique importance. Katz, following Hering, clearly noticed, how intimately ‘colour’ is interwoven with the organisation of ‘space’, as can be witnessed by his felicitous expression of a “marriage of colour and space”. Rich corresponding empirical evidence had been marshalled by Bühler, Kardos, Gelb, and Koffka. These authors also realised that the specific nature of these dependencies cannot, as often has been suggested within traditional accounts, be understood in terms of context-specific modifications with respect to rather elementary stimulus aspects, such as form, texture, etc. (cf. Mausfeld, 2003a, for a more detailed account of relevant findings). Gelb (1929, p. 672) regarded these dependencies as due to an “expression of a certain structural form of our perceptual visual world”, and Cassirer (1929, p. 155) due to the “very primordial format of organization.” In terms of the theoretical framework outlined above, these dependencies mirror the structural nature of the conceptual forms, in which ‘colour’-type parameters figure. These conceptual forms code our biologically given perceptual knowledge, which comprises a rich internal vocabulary for ‘material qualities’. These internal ‘material qualities’ go far beyond purely visibly definable attributes and are intrinsically transmodal in character, which again indicates the high degree of abstractness of the conceptual forms involved. They pertain, for instance, to ‘stability’, ‘tenacity’, ‘ruggedness’, or to attributes such as ‘lustrous’, ‘hard’, ‘juicy’, ‘dry’, and so forth.[26] The issue of ‘material qualities’ was almost entirely neglected in traditional accounts, because these attributes were erroneously conceived to be obtainable by some associative machinery from elementary sensory attributes. An early exception are lustrous appearances, first studied by Dove (1850), which were considered phenomena of great theoretical importance by Helmholtz, Hering, Kirschmann, Wundt, Bühler, or Katz.

Still, perceptual psychology mostly disregarded these phenomena as mere ‘side effects’ in perceptual psychology until in more recent years, where attention has been drawn to them from an entirely different, technological perspective. The recent interest in the perceptual bases for material appearances emerged from problems of rendering the corresponding qualities on a computer screen.[27] Attempts to identify relevant 2D image features that yield certain material appearances by mathematically analysing specific causally responsible physical properties of different types of material prove to be arduous and not very fruitful for perceptual purposes.[28] These analyses rather suggested that, as Fleming and Bülthoff (2005, p. 346) argued in the context of translucency, the physical regularities underlying the interaction of light and surfaces „are too complex for the visual system to estimate intrinsic physical parameters.“ Instead, as experimental studies in this context have indicated, complex perceptual surface qualities often have their specific and, with respect to the underlying physical regularities, often rather simple triggering conditions.[29] However, these and similar observations cannot be regarded as pertaining merely to problems of ‘cue’ integrations of image features. Rather they point to the inadequacy of all theoretical perspectives that downplay the complexity of the conceptual forms involved.

Classic studies on lustrous appearances already had shown that the types of sensory codes that are exploited by the internal vocabulary for material qualities are exceedingly variegated and idiosyncratic, and cannot be reduced to or understood from physical considerations of physical material properties. This is already obvious from Helmholtz’ (1867) well-know stimulus configuration for yielding lustrous appearances, as shown in fig. 3.

[26] See e.g. Schapp (1910), who drew attention to the fact that “one directly sees tenacity, brittleness, obdurateness, bluntness and many other attributes for which we lack linguistic descriptions…“, an ability he ascribed to a given rich internal vocabulary rather than to sensory-based associative processes.

[27] These problems have an interesting counterpart in art history. The simulation of material qualities on a canvass had been regarded as a particular challenge in painting, notably in Dutch renaissance art (Gombrich, 1976). Although already Alberti, in his *Trattato della pittura* (1435/1972), had recognized that by a proper juxtaposition of white and black only, the impressions of gold, silver and glass can be elicited, a realistic impression of material colours in painting turned out to be exceedingly difficult to achieve.

[28] as an example, see Koenderink & Pont (2002) for the case of velvet

[29] Corresponding observations can also be made with respect to the auditory perception of material qualities, where relatively elementary features are exploited as cues for complex material properties (e.g. Carello, Wagman & Turvey (2005).

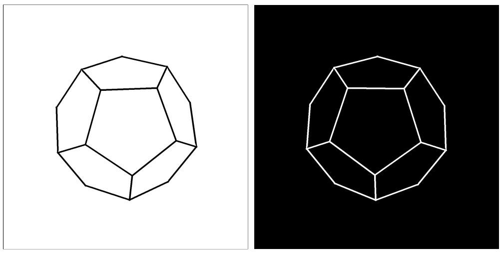

Fig. 3: Stereoscopic lustre

Under stereoscopic viewing conditions, the binocular combination of the two line drawings of inverted luminance contrast yields a vivid lustrous appearance. Similar appearances can be produced by a variety of different highly reduced stimulus configurations.[30] From corresponding studies, Bixby (1928) obtained instructive phenomenological descriptions of these appearances. Subjects describe them as "light and dark, somehow seen as if in the same place at the same time", "a sort of blending or fusion of light and dark", "a peculiar commingling or sifting-together of dark and light", or as "a bulky experience of luminous greyish white". Apparently, the sensory input pattern is sliced into perceptual layers, as it were, which pertain to conceptual forms of different types, namely to a 'surface' type and to an 'illumination'-type, whose specific interrelations result in the activation of the kind of 'surface'-type attribute that codes a specific internal 'material quality'. The great diversity of highly reduced stimulus configurations that give rise to lustrous appearances shows that material colour appearances cannot be derived from an analysis of the sensory-basis level. Rather, the internal logic underlying these appearances can only be revealed on the level of the *Perceptual System* and its conceptual forms. Hering (1879, p. 576) was guided by an intuition of this kind, which led him to propose what appears to be an essentially correct conjecture: Lustrous appearances arise, when there is a "surplus of light" with respect to the permissible values of the corresponding free parameters in the conceptual forms for 'surface' and 'ambient illumination', which yields a "cleavage of sensation" into shallow depth layers of an "essential" and an "accidental" colour component of a surface. The shallow depth segmentation[31] involved in almost all material colour appearances again is evidence for the "marriage of colour and space" in the internal coding of our rich vocabulary for material properties.

The neglect of material colours in traditional accounts of colour perception again testifies to the theoretical distortions that arose from the "errors of the application of colorimetric thinking to perception" (Evans, 1974, p. 197). The perceptual primacy, as it were, of material

[30] For instance, lustrous appearances can by obtained from spatially homogeneous haploscopically presented half-images of different temporal luminance modulations, or from monocularly viewed 3D-objects (e.g. polyeder), the luminance of whose spatially homogeneous faces is independently modulated (Mausfeld & Wendt, 2006).

[31] This depth segmentation can be obtained without any depth cues, as traditionally conceived, in the sensory input, or with the support of sensory codes for stereoscopic depth, as in the case of Helmholtz' display.

colours is also mirrored in the way we linguistically exploit the output of the *Perceptual System*. For instance, 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.” In the transition from the ancient Greek’s emphasis on forms of light, such as brightness, lustre, and the changeability of colours[32] to the subsequent culturally-shaped progression toward an increasingly abstract colour vocabulary, we can observe a shift from colour appearances as material properties and ‘forms of light’ to an abstractive notion of ‘colour per se’ as an intrinsic object property.

The notion of ‘colour per se’ as a unitary attribute has been abstracted in the course of a long technology-shaped cultural process. Although such an abstraction has its basis in perceptual achievements, it shares with a vast class of similar perceptual abstractions that it is essentially a cultural artefact. Of course, the fact that our cognitive capacities provide us with the means to arrive at an abstract notion of ‚colour per se’ is of interest and in need of explanation in itself. However, that we can cognitively attain the concept of ‘colour per se’ implies nothing as to the question, whether or not this concept plays any role in the computational structure of the perceptual system. The available evidence strongly suggests that it does not. In the context of perception theory, a corresponding conception of colour has veiled and obfuscated the important theoretical issues with which any account of colour perception has to cope.

[32] See e.g. Rowe (1974): „...the so-called ‘primitiveness’ of Greek colour-terminology can be seen as a reflection of a greater awareness of changeability of colours in the natural environment; an abstract vocabulary is in a real sense artificial, and in reducing the world of colour to a few simple categories, over-simplifies it, and robs it of its subtlety.“ It is hardly an exaggeration to say that “’colour’ did not mean to the Greeks what it means to us” (Irwin, 1974, p.14). Our present-day notions of ‘colour per se’ are the product of culturally shaped abstraction processes. “The Homeric Greek had not yet learned to think in abstract terms. ‘What is colour?’ is a question they would never have formulated, let alone been able to answer.” (Irwin, 1974, p.22)

References

Alberti, L.B. (1435/1972). *On Painting.* London: Penguin.

Arnauld, A. & Nicole, P. (1685/1996). *Logic or the Art of Thinking.* Cambridge: Cambridge University Press.

Bixby, F.L. (1928). A phenomenological study of luster. *Journal of General Psychology, 1,* 136-174.

Byrne, A. & Hilbert, D. (2003). Color realism and color science. *Behavioral and Brain Sciences, 26*, 3-21.

Carello, C., Wagman, J.B., & Turvey, M.T. (2005). Acoustic specification of object properties. In J.D.Anderson & B.F. Anderson (Eds.), *Moving image theory: Ecological considerations* (pp. 79-104). Carbondale, IL: Southern Illinois University Press.

Carroll, S.B. (2005). *Endless Forms Most Beautiful: The New Science of EvoDevo*. New York: Norton.

Cassirer, E. (1929). *Philosophie der symbolischen Formen. Dritter Teil: Phänomenologie der Erkenntnis.* Berlin: Bruno Cassirer.

Chen, H.S. & Rao, C.R.N. (1968). Polarization of light on reflection by some natural surfaces. *Journal of Physics, D: Applied Physics, 1,* 1191-1200.

Chomsky, N. (2000). *New Horizons in the Study of Language and Mind.* Cambridge: Cambridge University Press.

Cohen, J. (2003). Color: A functionalist proposal. *Philosophical Studies, 113*, 1-42.

Dove, H.W. (1850). Ueber die Ursachen des Glanzes und der Irradiation, abgeleitet aus chromatischen Versuchen mit dem Stereoskop. *Poggendorffs Annalen, 83,* 169-183.

Ekroll, V., Faul, F., Niederée, R. & Richter, E. (2002). The natural center of chromaticity space is not always achromatic: A new look on color induction. *Proceedings of the National Academy of Sciences of the U.S.A., 99*, 13352-13356.

Evans, R.M. (1974). *The Perception of Color.* New York: Wiley.

Fleming, R.W. & Bülthoff, H.H. (2005). Low-level image cues in the perception of translucent materials. *ACM Transactions on Applied Perception, 2*, 346-382.

Fodor, J.A. (2004). Having concepts: a brief refutation of the twentieth century, *Mind and Language*, 19, 29–47

Gelb, A. (1920). Über den Wegfall der Wahrnehmung von Oberflächenfarben. *Zeitschrift für Psychologie, 84,* 193-257.

Gelb, A. (1929). Die 'Farbenkonstanz' der Sehdinge. In: A. Bethe, G.v. Bergmann, G. Embden, & A. Ellinger (Eds.), *Handbuch der normalen und pathologischen Physiologie.* Bd.12, 1.Hälfte. Receptionsorgane II. (pp. 594-678). Berlin: Springer.

Gerhart, J. & Kirschner, M. (1997). *Cells, Embryos and Evolution: Toward a Cellular and Developmental Understanding of Phenotypic Variation and Evolutionary Adaptability.* Oxford: Blackwell.

Gombrich, E.H. (1976). *The Heritage of Appelles. Studies in the Art of the Renaissance.* Ithaka: Cornell University Press.

Grier, M. (2001). *Kant's Doctrin of Transcedental Illusion.* Cambridge: Cambridge University Press.

Hardin, C.L. (1988). *Color for Philosophers.* Indianapolis: Hackett.

Hartwell, L.H., Hopfield, J.J., Leibler, S. & Murray, A.W. (1999). From molecular to modular cell biology, *Nature, 402***,** C47–C52.

Helmholtz, H.v. (1855). Über das Sehen des Menschen. In: *Vorträge und Reden*. 4. Aufl., Bd.1, 1896. Braunschweig: Vieweg.

Helmholtz, H.v. (1867). *Handbuch der Physiologischen Optik*. Hamburg: Voss.

Hering, E. (1879). Der Raumsinn und die Bewegungen des Auges. In: L. Hermann (ed.), *Handbuch der Physiologie der Sinnesorgane, Bd. 3* (pp. 343-601). Leipzig: Vogel.

Hinzen, W. (2006). *Mind Design and Minimal Syntax.* Oxford: Oxford University Press.

Hochegger, R. (1884). *Die geschichtliche Entwicklung des Farbensinnes.* Innsbruck: Wagner'sche Universitätsbuchhandlung.

Irwin, E. (1974). *Colour Terms in Greek Poetry.* Toronto: Hakkert.

Jackson F. & Pargetter R. (1987). An objectivist's guide to subjectivism about color. *Revue Internationale de Philosphie*, *160*, 129-41.

Jones, L.A. (1953). The historical background and evolution of the Colorimetry Report. In: Commitee on Colorimetry (Eds.), *The Science of Color* (pp. 3-15). Washington: Optical Society of America.

Katz, D. (1911). *Die Erscheinungsweisen der Farben und ihre Beeinflussung durch die Individuelle Erfahrung.* Leipzig: Barth.

Kirschner, M., & Gerhart, J. (1998). Evolvability. *Proceedings of the National Academy of Sciences of the United States of America, 95,* 8420–8427.

Kitano, H. (2004). Biological robustness, *Nature Reviews Genetics, 5*, 826-837.

Koenderink, J.J. & Pont, S.C. (2002). The secret of velvety skin. *Special Issue on Human Modeling, Analysis and Synthesis of Machine Vision and Applications, 14*, 260–268.

Koffka, K., & Harrower, M. R. (1931). Colour and organization II. *Psychologische Forschung, 15*, 193-275.

Leslie, A., Xu, F., Tremoulet, P., & Scholl, B. (1998). Indexing and the object concept: developing ‚what' and ‚where' systems. *Trends in Cognitive Sciences, 2,* 10-18.

Martin, M.F. (1922). Film, surface, and bulky colors and their intermediates. *The American Journal of Psychology, 33*, 451-480.

Matthen, M. (1988). Biological functions and perceptual content. *The Journal of Philosophy*, 85, 5-27.

Matthen, M. (1999). The disunity of color. *The Philosophical Review*, *108,* 47-84.

Mausfeld, R. (1998). Color Perception: From Grassmann codes to a dual code for object and illumination colors. In: W. Backhaus, R. Kliegl, & J. Werner (Eds.), *Color Vision* (pp. 219-250). De Gruyter, Berlin/New York.

Mausfeld, R. (2002). The physicalistic trap in perception. In D. Heyer & R. Mausfeld (eds.), *Perception and the Physical World* (pp. 75-112). Chichester: Wiley.

Mausfeld, R. (2003a). 'Colour' as part of the format of two different perceptual primitives: The dual coding of colour. In: R. Mausfeld & D. Heyer (eds.), *Colour Perception: Mind and the Physical World.* Oxford: Oxford University Press.

Mausfeld, R. (2003b). Competing representations and the mental capacity for conjoint perspectives. In: H. Hecht, B. Schwartz, & M. Atherton (Eds.), *Inside Pictures: An Interdisciplinary Approach to Picture Perception.* Cambridge, Mass.: MIT Press.

Mausfeld, R. (in press a). The perception of material qualities and the internal semantics of the perceptual system. In: L. Albertazzi, G. van Tonder & D. Vishwanath (eds.), *Information in Perception.* Cambridge, Mass.: MIT Press.

Mausfeld, R. (in press b). Intrinsic multiperspectivity: On the architectural foundations of a distinctive mental capacity. In: Frensch, P. (ed.) *Proceedings of the XXIX International Congress of Psychology*, Berlin, 2008. Psychology Press.

Mausfeld, R., & Andres, J. (2002). Second order statistics of colour codes modulate transformations that effectuate varying degrees of scene invariance and illumination invariance, *Perception, 31,* 209-224.

Mausfeld, R., & Niederée, R. (1993). Inquiries into relational concepts of colour based on an incremental principle of colour coding for minimal relational stimuli. *Perception, 22*, 427-462.

Mausfeld, R. & Wendt, G. (2006). Material appearances under minimal stimulus conditions: Lustrous and glassy qualities. *Perception, 35, Suppl.,* 213-214.

Maxwell, G. (1968). Scientific methodology and the causal theory of perception. In: I. Lakatos & A. Musgrave (eds.) *Problems in the Philosophy of Science* (pp. 148-160). Amsterdam: North-Holland.

Maxwell, G. (1970). Theories, perception, and structural realism. In R.G. Colodny (ed.) *The Nature and Function of Scientific Theories* (pp. 3-34). Pittsburgh: University of Pittsburgh Press.

McLaughlin, B. (2003). The place of color in nature. In: R. Mausfeld & D. Heyer (eds.), *Colour Perception: Mind and the Physical World* (pp. 475-502). Oxford: Oxford University Press.

Neisser, U. (1976). *Cognition and Reality.* New York: Freeman.

Rowe, Ch. (1974). Conceptions of colour and colour symbolism in the ancient world. In: A. Portmann & R. Ritsema (eds.), *The Realms of Colour. Eranos Yearbook 1972, Vol. 41.* Leiden: Brill

Russell, B. (1927). *The Analysis of Matter*. London: George Allen & Unwin.

Santos, L.R., Hauser, M.D., Spelke, E.S. (2001). Recognition and categorization of biologically significant objects by rhesus monkeys *(Macaca mulatta)*: the domain of food, *Cognition, 82,* 127-155.

Schapp, W. (1919). *Beiträge zur Phänomenologie der Wahrnehmung*. Göttingen
Spelke, E.S. (2000). Core knowledge. *American Psychologist, 55,* 1233–1243.

Stewart, I. (1998). *Life's Other Secret. The New Mathematics of the Living World.* New York: Wiley.

Stoerig, P. (1998). Wavelength information processing versus color perception: Evidence from Blindsight and color-blind sight. In: W. Backhaus, R. Kliegl, J. Werner (eds.), *Color Vision* (pp. 130-147). Berlin: De Gruyter.

Strawson, G. (2003). Real materialism. In: L. Antony & N. Hornstein (eds.), *Chomsky and his Critics* (pp. 49-88). Oxford: Blackwell.

Wagner, G.P., Mezey, J. & Calabretta, R. (2005). Natural selection and the origin of modules. In: W. Callabaut & D. Rasskin-Gutman (Eds.), *Modularity. Understanding the Development and Evolution of Complex Natural Systems* (pp. 33-49). Cambridge, Mass.: MIT Press.

Wierzbicka, A. (1996). *Semantics. Primes and Universals*. Oxford: Oxford University Press.

Yolton, J.W. (1984). *Perceptual Acquaintance from Descartes to Reid*. Minneapolis: University of Minnesota Press.

Yolton, J.W. (1996). *Perception and Reality: A History from Descartes to Kant*. Ithaca: Cornell University Press.