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THE CONCEPT OF PERCEPTUAL 'FIELD' AND THE REVOLUTION IN COGNITION CAUSED BY KÖHLER´S PHYSISCHE GESTALTEN

The development of cognitive science at the beginning of the 20th century is characterised by several seemingly unrelated paradigms:

(i) the formalisation of perceptual and cognitive processes according to the model of Newton's *Principia*;
(ii) the development of theories of reasoning sharing with traditional approaches the distinction between procedures (rules) and content (semantics) but discarding logic as the 'true' form underlying human reasoning instead postulating ratiomorph processes; and finally
(iii) a novel approach to solve the old problem of the relation between sensations and perceptions and the corresponding bottom-up or top-down theories, namely Wolfgang Köhler's field theoretic approach of 1920 and Kurt Koffka's (1935) evolutionary account of the development of cognitive and perceptual processes of 1921 where the concept of 'Prägnanz' (in English: saliency or singularity, see Kanizsa and Luccio, 1986) describes the phenomenological 'pull' of percepts toward Gestalten comparable to the forces in an electromagnetic field.

The first two approaches correspond to the distinction of bottom-up and top-down processes in perception best exemplified by the dispute about colour theory at the beginning of the 19th century: Young postulated three simple filtering processes which transform electromagnetic waves between 380 and 750 nm into colours. In contrast to this position where the physical characteristics uniquely determine the percept, Goethe stressed in addition the importance of the 'entire nature' (*Farbenlehre*, preface) including the world knowledge of the perceiver. Helmholtz (1866) attempted to integrate these opposing approaches by postulating that, for instance, in the perception of objects, 'unconscious inferences' (top-down) are based upon sensations (bottom-up):

L. Albertazzi (ed.), The Dawn of Cognitive Science. Early European Contributors, 251–267.

An astronomer, for example, comes to real conclusions [...], when he computes the positions of the stars in space, their distances, etc., from the perspective images he has had of them at various times and as they are seen from different parts of the orbit of the earth. His conclusions are based on conscious knowledge of the laws of optics [...].

In the ordinary acts of vision [...] knowledge of optics is lacking. Still it may be permissible to speak of the psychic acts of ordinary perception as *unconscious conclusions*, thereby making a distinction of some sort between them and so-called conscious conclusions. And while it is true that there has been, and probably always will be, a measure of doubt as to the similarity between the results of such unconscious conclusions and those of conscious conclusions.[1]

In his influential treatise *The intelligent eye* (1970) Gregory reissued this inferential theory of perception specifying the nature of the 'unconscious inferences' as re-scalation and subsuming the phenomena observed by Gestalt psychologists as special cases. In the most recent edition of this book Gregory depicts the perceptual process as the result of a combination of the above mentioned approaches.

Gregory (1998) classifies the different approaches in the following way:

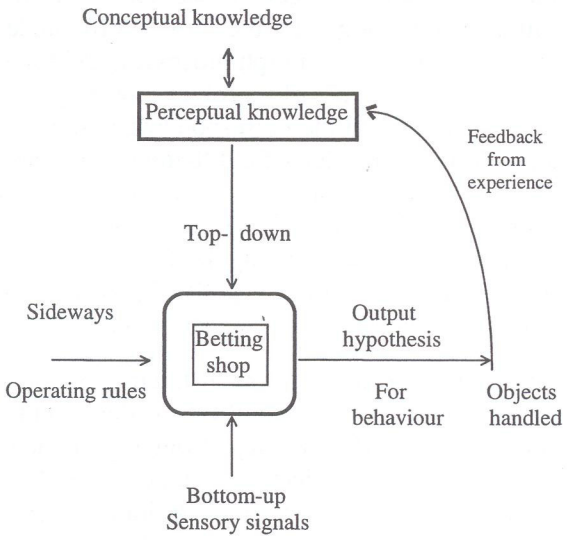

Figure 1: Gregory's (1995) model of the interaction of perceptual processes.[2]

In this classification the misleading impression emerges that Köhler's and Koffka's approach adds only one further level of analysis instead of resolving the traditional dichotomy,[3] furthermore the term 'rules' is misleading because of its Constructivist (top-down) connotation. What catches the Gestalt theoretic intentions better is the term constraints, insofar as perceptual and cognitive

processes are the result of the evolution of mechanisms successful in the co-ordination of organisms and their environment; this motivates the following modification of Gregory's model:

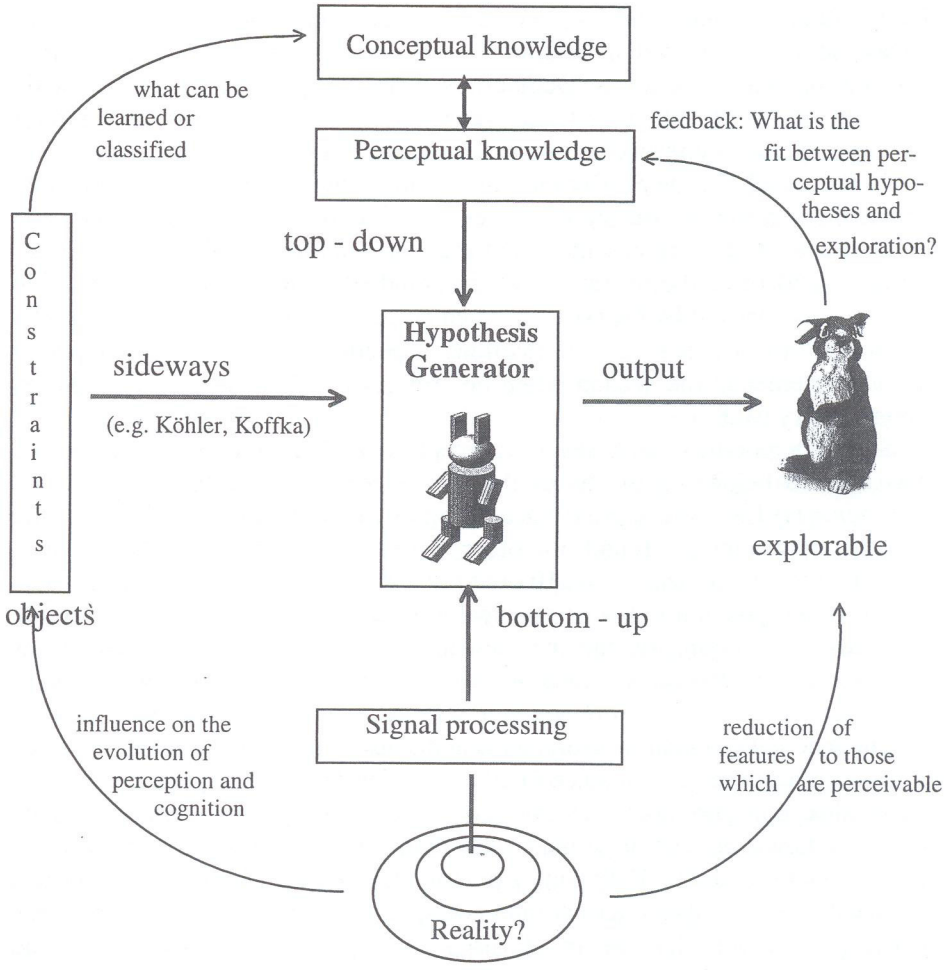

Figure 2: Modification of Gregory's classification of different approaches to perception.

The first formulation of the dichotomy between top-down and bottom-up approaches to perception and the implicit position that this dichotomy cannot be resolved by reducing it to the one or the other alternative can be found in a fragment of Democritus cited by Sextus Empiricus:

> The concepts 'coloured', 'sweet', 'bitter' are mere conventions. In reality there are only atoms and the void. 'Poor mind' *thus Democritus lets the senses address the mind* 'from us you get the foundations of your reasoning which you apply to undermine us! Trying to destroy us, you destroy yourself.

By pointing out that percepts (αιγδισιζ) as phenomenologically given have always to be interpreted in relation to a frame of reference which in turn depends on past experience, Democritus refutes any entirely Reductionistic approach to epistemology – from the Miletic School to the foundation of Carnap's 'Einheitswissenschaft' on observational sentences.

In the cited fragment Democritus, furthermore, indicates the principal problem for a unitary theory of perception, that is, reducing all phenomena either to the veridical representation of the world in the sensations (the bottom-up approach) or to the operations of the mind (the top-down approach). The first view is attacked by Democritus when he points out that colours, tastes etc. are mere 'νομοι', that is, classifications depending on cultural traditions or social agreements; the second when he stresses the dependence of cognition upon sensory data.

Since Democritus, analyses of perception and cognition can easily be classified as belonging to one of the two alternatives. Starting with Plato's (*praeter rem*) Idealistic approach according to which the meaning precedes the objects, epistemology found its other extreme in Roscelin's Nominalism according to which meaning is affixed to objects arbitrarily – *post rem*, one can find a similar position in Locke's radical Reductionistic approach to perception and reasoning relying on the mechanistic principle of contiguity which has been refuted by Berkeley's famous example of triangles being perceived as such even if never seen before which in turn led to a radical Idealist position.

The fact that physical measurements and sensory perceptions differ has been a truism in science at least since Galilei who derided their importance as "non sieno altro che puri nomi" (*Il saggiatore*) but the epistemological problem remained how a perception of reality can evolve if the sense data upon which it relies are so unreliable. Following Epicurus, Gassendi stated that all empirical knowledge (in Scholastic terms: intellectus) relies on data from the senses not denying, however, that the mind *ratiocinatio* possesses its own rules and thereby modifies the sensory perceptions (thus Leibniz added to Gassendi´s "nihil in intellectu nisi prius in sensu" the qualification "[...] nisi intellectus ipse").

This sceptical view of the limitations inherent in founding science upon sensations can still be found in Kant's *Prolegomena* where he denies the possibility of psychology as a natural science. Reacting against this view, psychophysics developed in the 19th century with its inherent postulate that sensations depict reality in a way comparable to measuring devices: namely that, in loudness, brightness, or weight, sensations are mere logarithmic transformations of the corresponding physical measurements and that even the apparent arbitrariness of colour and taste can be attributed to the fact that these are not unitary but multidimensional variables.

In general, the development of experimental psychology in the 19th century attempted to answer two problems posed by Kant: (i) Psychophysics, especially Fechner's logarithmic transformation of physical stimuli into well defined sensations, demonstrated successfully that psychology can be treated mathematically,[4] and (ii) the schema underlying the Kantian categories in the *Critique of Pure Reason* was identified as the cognitive process co-ordinating images' as measured in psychophysics with concepts as identified by introspection. Thus defining two methodologically distinct psychologies.

When in 1834 Ernst H. Weber was able to show empirically that for sensory data the general rule seems to hold that the ratio between a just noticeable difference of a physical change and the amount of the physical stimulation is a constant ($k = \Delta R:R$) and Fechner in 1860 interpreted this Δ as a differential, the relation between physical data and sensory perception could then be described as $\varphi = c \log \psi$. The consequence of this approach was that Newton's linear model for physics, especially the additivity of forces, could be applied to sensory data, too; this becomes apparent in the vector analytic approach to colour vision by Grassmann and later in Kurt Lewin's vector analysis of the behaviour of people in the environment upon which they act. What this approach could not model in perception, namely the phenomena of constancy, was attributed to the inborn characteristics of the mind (the above mentioned Scholastic ratiocinatio) or – in modern terms – Helmholtz unconscious inferences.

This tradition is still evident in the theories of human information processing where data driven and concept driven processes are assumed to interact in analogy to the computer where programs act upon data (by the way, John v. Neumann, the architect of modern computers, has proposed to use the architecture of computing machines as a model for the human mind, thereby taking up ideas developed for instance by Leibniz and implicit in the theory of thinking of Otto Selz, finally made explicit in the Newell-Simon model of information processing).

However, when Helmholtz (1866) introduced the concept of 'unconscious inferences' in order to explain phenomena like illusory motion (Plateau) and geometric-optical illusions, he took up again the dual view of perception as described by Democritus, namely, that top-down processes (reason, in Aristotelian philosophy) and bottom-up processes (sensations) *together* produce the percept.
In this he was perhaps influenced by Hegel's dialectics:

> The necessity and the wit of man has invented infinitely manifold ways of using and mastering nature.... Whichever forces even nature has produced and released against man, coldness, beasts, water, fire – he knows means against them, these means he takes out of [nature] itself and uses them against it; the cunning of his reason allows that he uses natural objects against natural forces and by pitting them against each other preserves himself.[5]

Hegel's classification of sensory processes which can be seen in analogy to physical measuring devices and therefore open to experimental investigation, and cognitive processes which rely on the active and conscious mind and therefore have to be investigated by introspection, can be interpreted as a first attempt to resolve the classical dichotomy by means of dialectics. A later offspring of this approach can be found in the Soviet 'Activity psychology' (especially Leontiev, 1973) in which the ascending, that is, the stimulus controlled part of cognitive processes is modelled according to Pavlov's Associationistic theory of the first and the second system of signalling and the descending part of actions is driven by reason which mould and modify nature with the result of an increasingly better fit between reality and cognition. Similar ideas can be found in Roger Shepard's (1981) view of psycho-physical complementarity according to which "(1) The world appears the way it does because we are the way we are, and (2) we are the way we are because we have evolved in a world that is the way it is" (p. 332).

A more direct influence of Hegel´s position can be found in Wundt's seemingly neat solution for the question of top-down or bottom-up processing by locating them as qualitatively different functions on different levels in the hierarchy of mental processes and making them incomparable because of his claim that they have to be investigated by different methods. This claim was challenged by Hermann Ebbinghaus (1885), who was able to show that even 'higher cognitive functions' can be investigated by experimental methods but also that these functions, namely, learning and forgetting processes, can be modelled mathematically. However, in one crucial point Hermann Ebbinghaus deviated from the tradition in psychophysics: He did not borrow his mathematical model from physics but from biology, that is, he interpreted forgetting as decay and learning as growth and chose the Euler function as the appropriate experimental function with a negative exponent, namely time. The

computation showed that the entire scope of mental processes can be investigated experimentally and that – a least in principle – they can be modelled formally.

Mach's observation of melodies as invariant forms independent from the physical characteristics of the constituting tones at first seemed to shatter the assumptions underlying psychophysics and Associationism, however Ehrenfels' theory of 'Gestaltqualitäten' and Meinong's (1891) theory of relations seemingly resolved this problem because they identified 'Gestalten' as invariant in relations thereby preserving the linear approach of Associationism by regarding associations between relations as constituent for form perception. Any further inconsistencies, as for instance optical illusions and apparent motion, were discarded as consequences of erroneous top-down-processes, that is, Helmholtzian unconscious inferences.

That the concept of invariants in its strict sense does not resolve the dichotomy between bottom-up and top-down approaches to cognition can be seen from the fact that a melody has to be well formed in order to be transposable, however, what constitutes well-formedness depends not only on physically describable characteristics of the melody but also on the cultural and/or cognitive background of the listener; intercultural comparisons in music show beside a few universals in harmonics a striking variability in rhythm and tonality. Furthermore, the fundamental problem in perception is the separation of signal from noise,[6] that is, why and under which conditions a melody remains recognisable even if it is sung out of tune or against a background of noise.

In order to resolve the impasse created by Wundt's dualistic position towards mental processes and the shortcomings of relationalism it was necessary to give up the mechanistic model underlying association theory and its further developments. As early as 1909, Wolfgang Köhler writes to his gymnasium professor in physics, Hans Geitel, in a comment on Hans Witte's attack against Ernst Haeckel's philosophical monism:

> a unitary system of physics in which all processes in nature are traced back to electrical state transitions, can – in principle – lead as well to 'Materialismus' as the.[traditional system of] mechanics. In our days it would seem only more elegant and therefore more tempting.[7]

Köhler's experiments for his doctoral dissertation '*Akustische Untersuchungen I*', 1909) had forced him to apply modern electro-magnetic technology and to develop some new methods himself (see his contribution to the *Festschrift for Julius Elster and Hans Geitel* of 1915). His background in physics and his experiences as principal investigator at the primate centre of the Prussian Academy of Sciences in Tenerife prepared him to suggest a generalised field concept as the unifying principle for natural philosophy which

was published under the title *Die physischen Gestalten in Ruhe und im stationären Zustand. Eine naturphilosophische Untersuchung* in 1920.

Despite the attacks on the implicit equating of psychophysics with perception (Bergson, 1911) the linearity assumptions underlying classical mechanics had remained dominant for theory building in psychology with the exception of Köhler's modelling of psychological and brain processes according to Faraday's and Maxwell's theory of electromagnetic fields. Köhler reports that Wertheimer's experiments with apparent movement, especially the φ–phenomenon, have led him to apply the concept of the electromagnetic field to processes in perception.

Usually, the concept of 'field' is regarded as characteristic of Wolfgang Köhler's attempt to give a consistent theoretical framework for Gestalt theory. However the concept of 'field' pervades the philosophical and psychological treatises on perception in the 19th century. For instance, in Husserl's 'Dingvorlesung' in 1907 a highly detailed systematisation of the inter-dependency of different perceptual fields was developed (see figure 3).

Köhler's theory of 1920 differs from these earlier field-theoretic approaches to perception and action; he starts from Maxwell's concept of the electro-magnetic field, whereas, in contrast, the standard psycho-physical approach of the 19th century had assumed that the basic constituents of a perceptual field are sensations which can be interpreted as forces in a linear Newtonian vector field. As early as 1913 in his *Über unbemerkte Empfindungen und Urteilstäuschungen* Köhler attacked this basic assumption by pointing out that so-called illusions can neither be explained by reference to errors of judgement,[8] nor by Cornelius' unnoticed sensations.[9] Köhler asks:

> How could creatures survive who would be informed about reality by sensations corresponding so little to it? How could these creatures construct a useful physics, since sensations necessarily constitute the primary material of this science? [...] none of us experience possibilities of harm in the Müller-Lyer illusion, the 'apparent' unity of a sound, the octave illusions, whether of judgement or sensation, are biologically completely indifferent, insofar as they are not of tremendous value[...][10]

Following Bergson (1911) he then points out the limited role sense perceptions play in physical laboratories and he finishes:

> from the existence of physics, therefore, no more can be concluded than these cases of perception important for physics permit, namely that these cases correspond to the 'basic assumption'. Whether the whole field of sensations and perceptions conforms to the basic assumption cannot at all be decided by the existence of physics.[11]

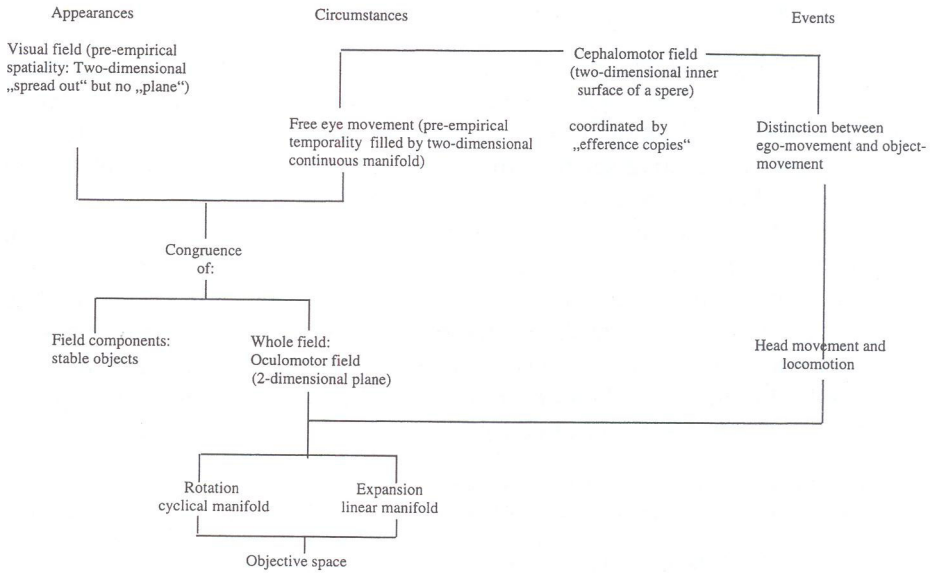

Figure 3: Schema of interrelated perceptual fields as developed in Husserl's Dingvorlesung (Thing and space)

Köhler's solution for the fact that illusions are pervasive and cannot be avoided even by Schumann's 'isolation in consciousness' but at the same time do not prevent a successful interaction with our environment, appears first in a

footnote "This fact might easily be explained if we regard as the 'immediately given,' and in any case as the biologically primary 'reality,' not 'sensations,' but (for the most part) 'things.'"[12] Köhler's choice to put this argument into a mere footnote shows that he was aware of the revolutionary character of his explanation. By pointing out that the most simple relations between stimulus and sensation constitute "limiting cases achieved by means of isolation" but do not suffice to explain "the everyday perception of *things*," he finishes his contribution by stating:

> Anyone can see that the theory of perception will at first become less simple in this way. But research so oriented will also find laws and constants in the greater richness of its material and perhaps will finally be able to attain a deeper understanding of the whole field than can be achieved by means of the assumptions which we have opposed.[13]

Köhler's arguments contain the theoretical kernel of Gibson's (1979) later theory of ecological perception which – influenced by Kurt Koffka – James Gibson started to develop just after the end of the critical period for the development of cognitive sciences discussed in his book. By the postulation of *things* as the basic constituents of perception Köhler points into the future of experimental psychology, his reference to Brentano's "unitary nature of judgement experiences" (p. 33) reveals the motivation for Köhler to develop the concept of the perceptual field into a theory which goes beyond the limiting case of pure stimulus-sensation relations as investigated in the field of psychophysics. In Köhler's last scientific paper "Gestalt psychology" published 1967 in *Psychologische Forschung,* he explains which reasons had led him to develop his theory of generalised potential fields of 1920:

> The Gestalt psychologists, we remember, were always disturbed by a thesis which was widely accepted by others. One psychologist, strongly influenced by traditional convictions, had formulated it in the following words: "I do not know whether perceptual fields actually consist of independent local elements, the so-called sensations. But, as scientists, we have to proceed as though this were true. An extraordinary statement – an a priori general conviction about the right procedure in science is assumed to be more important than the nature of the facts which we are investigating.
>
> From its very beginning, Gestalt psychology ignored this thesis and began its work with simple and unbiased observations of facts. Independent local sensations? Consider again what happens in apparent movement. After a first visual object has appeared in one place, a second visual object does not appear in its normal location but nearer the place where the first has just disappeared, and only then moves towards what I just called its normal location. Clearly, therefore, the process corresponding to the second object has been deflected, has been attracted by a remnant of what has just happened in another place, the place of the first object, and has only then approached its 'normal' location. Consequently, under the conditions of such experiments, the second object does not behave as though it were an independent local fact at all. The statement, quoted earlier, that perceptual fields must be assumed to consist of independent local sensations, is therefore at odds with the behaviour of percepts even under

such fairly simple conditions. Or take any of the well-known perceptual illusions, say the Müller-Lyer illusion. Can there be any doubt that in this case two lines of objectively equal length become lines of different length under the influence of the angles added at the ends of the distances to be compared? And so on, in a long list of examples, all of them incompatible with the statement about the nature of perceptual fields.

Ours was an uphill fight. I felt greatly relieved, as mentioned above, to find so fundamentally similar an approach from the side of physics. In his great treatise, *Electricity and Magnetism,* Clerk Maxwell had remarked that we are often told that in science we must, first of all, investigate the properties of very small local places one after another, and only when this has been done can we permit ourselves to consider how more complicated situations result from what we have found in those elements. This procedure, he added, ignores the fact that many phenomena in nature can only be understood when we inspect not so-called elements but fairly large regions.[14]

The field-theoretic concept Köhler (1920) developed for the interaction of forces in biological and psychological systems departed strongly from the linear 'field' concepts which dominated psychology and phenomenology at the turn of the century, because even for the seemingly most simple case of stationary states he postulated non-linear interactions and the minimum principle as the driving force for self organisation. Up to then the fact that light propagates linearly and that its energy dissipates quadratically as gravitation had led to an implicit model of psychological processes which is constituted by independent part interacting like forces in the vector field or – on a qualitative level – which consists of building blocks organised in decomposable hierarchies.[15]

Why the field theoretic concept was so revolutionary can be seen from the fact that even Helmholtz initially reacted strongly against Faraday's description of field processes. The background of his and others' resistance against non-linear processes in physics can be traced back to the fact that these approaches smacked of Cartesian 'vortices,' originally proposed for gravitational processes which were shown by Newton to be linear, but now re-emerging again in the field of electromagnetics. It took the development of Maxwell's formal apparatus to convince physicists like Helmholtz; as late as 1881 he finally wrote:

[...] we see how great a degree of exactness and precision was really hidden behind the words, which to Faraday's contemporaries appeared either vague or obscure [...] I have no intention of blaming his contemporaries, for I confess that many times I have myself sat hopelessly looking upon some paragraph of Faraday's descriptions of lines of force, or of the galvanic current being an axis of power.[16]

Insofar it was not astonishing that Köhler's proposal met with resistance or even in the greater part with indifference because it was generally assumed that even if these non-linear processes existed they were confined to a small area in psychology and therefore not necessitating a general theoretic approach.[17]

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One can argue that the ingredients of today's theory of perception as exemplified in the integrative account (in Figure 2) were all present in the first part of the 20th century: (i) the core concept of perceiving invariances as the solution of the problem that the sense impressions vary from time to time and place to place but the perceived world is relatively stable; this solution was implicit in the theoretical framework of the Graz School of Gestalt Theory and can also be found in the writings of Koffka from the Berlin School; (ii) the ability to separate signals from noise, that is, to see patterns (*Gestalten*) behind and out of uninformative local sense impressions could be accounted for by Köhler's field theory for biological and physical phenomena; and finally (iii) the enhancement of contours as shown in Mach bands and Hering's demonstrations of simultaneous contrast could explain why the human perceiver is able to perceive differences where even highly accurate measurement devices fail.

The problem for a development of a full-fledged theory of perception at the beginning of this century was that these different results were not regarded as complementary but as competitive accounts for what perception really is. Modern research in psychophysiology indicates that the physiological processes correlated with these different levels of perception can be regarded as hierarchically ordered: (i) Already in the retina, lateral inhibition occurs which not only accounts for Mach bands and contrast effects but also for the effect that the percept is more fine grained than the receptor structure of the retina, as can be shown in the effect of Vernier acuity. (ii) The innate Gestalt forming mechanisms as postulated by Tembrock,[18] seem to have been identified by Eckhorn and co-workers (1990) and Gray, Engel, König and Singer (1992) as highly correlated excitation patterns in the brain at relatively distant areas of the cortex; these correlations of 40 Hertz oscillations in excitation may constitute the percept of unitary objects which is phenomenological prior to the perception of features. (iii) Due to the feature of self-referentiality [19] these processes can explain why for instance in a movie version of Figure 4 the dog is perceived immediately and separated from the 'noisy' environment without any effort while – in contrast – the inspection of the static form or one where only the parts belonging to the dog are moved homogeneously necessitates 'scrutiny' in order to identify the object.

Figure 4: A hidden figure (Dalmatian dog)

Finally, the tuning of perception to invariants seems to be controlled in the right hemisphere of the brain. Admittedly, the higher the level of form perception is the more disputed are the correlated physiological and brain anatomical problem is that the interactive structure of the brain processes contributing to the stable perceptual representation of the world does not have a simple hierarchical structure with its appealing feature of decomposability but seems to be heterarchical in character; for instance Goodale and Milner (1992) show that the pathways proposed by Trevarthen (1968) and seemingly supported by the experimental results of Mishkin and Ungerleider (1982) do not lead to the proposed anatomically separable modules of form vs. location identification but that even on this level there exist interaction. Also on the phenomenological and behavioural level it can be shown that – for instance – the clear-cut hierarchical model of David Marr (1982) does not hold: Already Schumann's (1904) results that contours are perceivable even if no physical differences exist (which later led to Kanizsa´s 'illusory contours') indicate that the perceivability of patterns (in the sense of *Prägnanz*, that is, being a minimum in a potential field) influences even processes on a lower level of perception.[20]

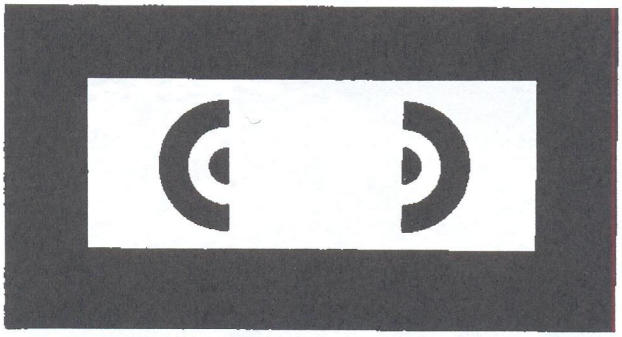

Figure 5: First example of illusory contours analysed in the framework of perception (Schumann, 1904).

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NOTES

[1] Helmholtz 1866, as cited in Johnson-Laird and Wason, 341.
[2] Gregory 1998, 208, comments on this schema "Ins and outs of vision. Not to be taken too literally, this is a way of relating the notions of *bottom-up* signals from the eyes, *top-down* knowledge, and what we are calling *sideways* rules of perception, such as the Gestalt laws of organisation and perspective. This is developed in Chapter 11, 'Speculations,' with an attempt to classify illusions."
[3] See Henle 1987, for the position that the resolution of dichotomies is a central tenet of Gestalt theory.
[4] It should be noted, however, that in his Prolegomena he referred only to the introspective method. In contrast to Wolff's definition of psychology Kant regarded empirical anthropology based upon observable behaviour as a natural science. Insofar, Kant can be regarded as a proponent of the 'methodological behaviourism' of modern cognitive science.
[5] Hegel 1830, 13ff.
[6] Swets,1961.
[7] See Jaeger 1988, 33
[8] See Benussi 1904, or Stumpf 1910.
[9] See Schumann 1912.
[10] Köhler 1913, 76.

[11] Ibidem, 77.
[12] Ivi, footnote 1.
[13] Ibidem, 79–80.
[14] Köhler 1967, 112/113.
[15] How strong this appeal of a strictly linear model for psychology is can be seen from the fact that the dominating theory in cognitive psychology from about 1960 up to the end of the 80's, namely, information processing, is best described by the additive factor model. Cf. Sanders 1998.
[16] Cited after Singer 1959, 433.
[17] David Marr's book of 1980 shows this because in his inherently linear modelling of bottom-up perceptual processes he lists the Gestalt factors of grouping but a uses them as entirely isolated modules, the implicitly non-linear character of them having no bearing on the general linear information processing account.
[18] Tembrock 1973, 123.
[19] See Roth 1992.
[20] v.d. Heydt, Peterhans, Baumgartner, 1984 have been able to identify where in the brain this interaction happens.

FIGURE CAPTIONS

Figure. 1: Gregory's (1995) model of the interaction of perceptual processes.
Figure 2: Modification of Gregory's classification of different approaches to perception.
Figure 3: Schema of interrelated perceptual fields as developed in Husserl's "Dingvorlesung".
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