THE INTERACTION BETWEEN THEORY AND DATA IN SCIENCE

Exploring a New Model for Perception in an Application to Harvey's Discovery of the Circulation of the Blood

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Nothing is harder to pin down than the way we 'see' objects of which we know the shape

E. H. GOMBRICH, *The Sense of Order*, Oxford, Phaidon, 1979, p. 164

The theory-laden character of scientific observation in both sociology of science (see e.g. Mulkay (1)) and philosophy of science (see e.g. Shimony (2)) is now generally accepted. However, it cannot be claimed that the details of the interaction between theory and data are fully understood. Somehow, the idea is accepted as a general principle while its application remains puzzling and paradoxical. Based on developments in AI (artificial intelligence) and cognitive psychology, this paper explores new ideas about perception which lead to a model for interaction between theory and data. In order to investigate its potential relevance for science studies, it is applied to a historical case in history of science: the role of theory and data in Harvey's discovery of the circulation of the blood.

Theory-Ladenness

If what we observe depends on what we except to occur, how can we discover anything new? If observation is theory-laden, how can we ever adapt theories to new data? Since the 1960's, the theme of the theory-laden character of data has been widely accepted. Beside Hanson, who coined the phrase *All data are theory-laden*, authors like Kuhn, Polanyi, Toulmin, and Feyerabend

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promoted the idea of scientific observation as strongly influenced by large conceptual systems of a more theoretical nature. This is contrary to what has been called the 'orthodox' view of theories. According to that view, scientific theories are free-floating entities which increase in acceptability to the degree they can be anchored to the solid 'soil' of observation. Observation is independent of theories. It constitutes the rock bottom on which scientific theories should be founded (see Feigl (3)).

With respect to the theory-dependency of observations, one can distinguish between a *logical* and a *psychological* approach.

The logical approach goes back on authors such as Duhem, Quine and Feyerabend. It simply states that, even if we can make a neat distinction between the observations and the theoretical statements of a particular theory in science, we always *depend on* an auxiliary *theory* of perception to indicate what we regard as observations. So there seems no escape from circularity. As such, the notion of theory-dependency of observation is a somewhat disheartening principle which extinguishes the hope of ultimate verification and the anchoring of theories in the solid soil of observation.

The psychological approach is more directed by the wish to understand how new knowledge is formed than by the need to justify acquired knowledge. The guiding function of theory is the focus of attention here. It shapes expectations so that perception can be highly selective and specific. If it is, in Einstein's terms "the theory which decides what we can observe" (4) then the question becomes, how do the abstract terms of a theory interact with concrete sensible things? How can a theory penetrate into observation processes? In this paper, we will follow a psychological approach and attempt to clarify the relationship between theory and data by means of some currently new ideas on visual perception.

The Celebrated Exemplars

Demonstrations of the theory-dependency of observation provided by Hanson and Kuhn refer often to the classical ambiguous figures familiar from so many textbooks on perception. One of the most famous ones – the Necker cube – goes back to an authentic experience with scientific observations. Necker hit upon the ambiguity of this image while studying figures of cristalline forms (5). Other celebrated examples are Rubin's figure-ground reversal which alternates between a goblet and a pair of face profiles, Boring's "young girl-old woman" reversal and the rabbit-duck figure developed by Jastrow in 1900 (see Figure 1).

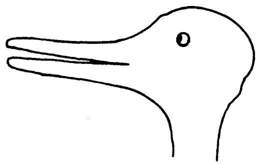

Fig. 1. Jastrow's rabbit-duck figure (1900).

Kuhn repeatedly emphasizes the exemplary nature of these apparently simple reversals for the understanding of conceptual changes in scientific revolutions. In his chapter on such revolutions as changes of world view, he indicates that

> scientists see new and different things when looking with familiar instruments in places where they looked before. . . . It is as elementary prototypes for these transformations of the scientist's world that the familiar demonstrations of a switch in visual gestalt prove so suggestive. *What were ducks in the scientist's world before the revolution are rabbits afterwards. The man who first saw the exterior of the box from above later sees its interior from below* (6) (italics added).

Despite the popularity of such ambiguous figures in even elementary psychology textbooks, few of them offer a thorough discussion of the problems involved. In this paper we will combine some lines of research in the psychology of perception (in particular Arnheim, Gibson and Palmer) to suggest a model that could account for the gestalt switch experiences. One of the reasons for the promising character of the model is that it is highly suggestive with respect to how Kuhn's and Hanson's reference to the phenomenon should be understood.

Perception and Knowledge

Among the publications that have emphasized the central importance of such ambiguities as the *rabbit-duck*, E. Gombrich's *Art and Illusion* (7) stands out as a most eloquent and convincing argument for what could be called a *two-component* model of perception. Already in Aristotle's analysis of the notion of experience, observation is described as a combination of sense perception and memory. Perception is the interpretation of sense data on the basis of stored knowledge retained from previous encounters with the object of perception. Current cognitive orientations in both psychology and AI tend to stress the relative contribution of stored knowledge at the risk of loosing sight of the data. Gombrich's book is a penetrating attempt to "disentangle what we really see from what we merely know" in the perception of art. Though pictures should not be looked upon as substitutes for visual objects, we can hope to derive useful suggestions for a theory of perception from an analysis of "the beholder's share in the reading of an artist's image". According to Gombrich "ambiguity – rabbit or duck? – is clearly the key to the whole problem of image reading" (8). In the course of a fascinating study of the development from the conceptual art of Egypt to a "gradual adjustment to natural appearances" in Greek art, the comparable development from schematic medieval art to the "constant search" and "sacred discontent" brought in by the Renaissance, and similar issues in modern art (e.g. impressionism vs. cubism), he accumulates numerous examples to argue for the acceptance of what could be called the *Bartlett-model.* Bartlett's 1932-book (9) studies remembering in human subjects for both verbal and pictorial material. The general result is the notion of a *memory scheme.*

Knowledge is stored in memory in terms of some general *schemes*, accepted conventional representations for various instantiations of objects or events. The scheme embodies the basic conceptual knowledge about objects or events. In memory it constitutes the framework for the reconstruction of what has been seen. In perception, it constitutes the "beholder's share", the skeleton brought in by the perceiver to assimilate the detailed information so generously offered by the perceptual world. This notion of scheme can be found back in current cognitive science under various names and implementations as e.g. Minsky's concept of *frame* (10). Such views express a cognitive trend in that they suggest that the substantial component in an act of perception is brought in by the subject (in terms of knowledge) while local colour and appearance are brought in by the object (in terms of sensations). However, no details are provided with respect to the mechanism of the interaction between knowledge and sensation. Obviously, the cognitive orientation is superior to the uni-directional causal chain model of crude empiricism. There perception is related to events in the outside world which, according to a kind of domino theory, trigger a series of causal connections ending in an event in the brain associated with the mental state of perception. In the cognitive view, the inward bound chain of causal events is supposed to be met by outward bound schemes embodying expectations so that there are indeed contributions from both subject and object. But again, how are we to conceive of their interaction? Could we think of the subject as a source of expectations irradiating schemes in all directions while bombarded from all sides with data and should we reduce genuine perception to those happy collisions where data fit expectations? Even if the collision model would seem plausible, it does not contribute substantially to our understanding of the perception of ambiguous figures. In that respect, a finding of Leeper (11) is highly significant. Using Boring's *young girl–old woman*, Leeper found that conceptually induced expectations were not very effective in orienting perception towards a specific interpretation of the ambiguous picture. Even when the experimentalist tells his subject to look for a young woman, the subject might hit upon the old woman interpretation and remain temporarily unable to find any other possibility. How then do perceptual data and conceptual entities interlock? A more subtle model is needed than just a scheme to be augmented with detail.

The New Perceptual Elements

The notion of point-like sense-data as the micro-units of perception has been criticized from several sides. Gombrich does away with it as the untenable *mosaic* approach, however without providing a clear and workable alternative. Like the gestalt psychologists, Gibson, for several decades the most acute student of perception, rejected these units of analysis already in his 1950-book as "nothing but geometric fictions" and "sensory elements" that "could never be specified" (12). In his more recent publications and especially in his new book *The Ecological Approach to Visual Perception* (13), one of the major units of analysis is the "ambient optic array" which is in all respects, the antipode of the isolated sensation. We discuss the perception of objects as if the *figure-ground* separation is an automatic and unproblematic achievement of our perceptual system. But it is as much a challenge to explain how an object is identified and separated out of the enormous complexity of a visual array as it is to construct an object from elementary sensations. The new approach which we discuss in this paper is compatible with the array-approach and leans on what Gibson discusses as the principle of nesting, in particular nested visual angles.

In order to appreciate the new ideas about visual perception, it is instructive to review the recent history of pattern recognition and picture processing in AI.

In a very orthodox empiricist way, computer picture processing started with the mosaic model that turns out to be so misleading. In fact, our current T.V. sets still operate on that basis. Scenes are recorded by means of a camera and the recorded picture is projected on a grid-like structure. There the image is decomposed into a huge number of matrix cells which register in terms of a single value the recorded intensity of light for that particular cell. Images are reconstructed by reproducing the light intensity corresponding to the registered value in a similar matrix element. As with photographs, the quality of the reconstruction is considered directly related to the size of these granular elements. The finer the grain, the more precise the image. However, perception is not the encoding and reconstruction of images and developments in AI have shown that low level of resolution information is as important as high level of resolution information. Lipkin and Rosenfeld's collection on picture processing (14) distinguishes between three classes of relevant variables: contrast and border, shape and geometry, and texture. Roughly, these variables correspond to three different levels of resolution and/or visual angle. The psychologist Palmer (15) has in line with AI experience, convincingly demonstrated that object perception involves a combination of such levels.

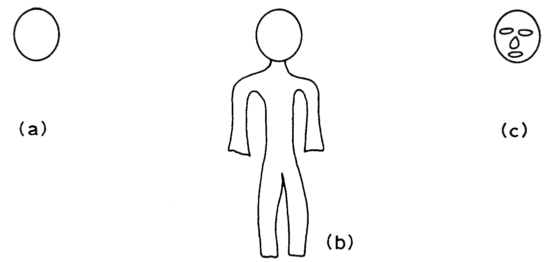

Fig. 2. Apparently meaningless forms such as (a) acquire a quite definite interpretation when embedded in a larger figure as in (b) or when filled in with details as in (c) (after Palmer, 1975).

Take an elliptical structure as exemplified in Figure 2(a). In principle, it can represent a variety of objects with that kind of outline, e.g. a boulder, an egg, a head, a kind of fruit. However, if it is joined to the shape indicated in Figure 2(b), ambiguity disappears and it clearly becomes the representation of a head. The same occurs however when the elliptical form is filled in with the kind of detail indicated in Figure 2(c). On its own, each of the forms involved is highly ambiguous and abstract. Used in combination, specifying entities at different visual angles, they allow for the straightforward identification of an object. Palmer (16) has generalized this scheme in terms of three levels of units involved in the pictorial representation of objects:
– the *whole* figure specified in terms of a closed edge or outline;
– the multisegment *parts* specified in terms of internal contours or edges;
– the individual line segments specified in terms of texture, i.e. the uniform granular aspect of surfaces.

According to this scheme, each object can be seen as a concatenation of forms related in terms of part-whole relationships which are of a conceptual nature. Triggered by some particular features suggesting a specific local interpretation at some level, recognition can be thought of as extending along a conceptual ladder in order to generate specific expectations at another level. If some dots and dashes in a confusing picture suggest two eyes and a nose, we should look out for the circular shape of the head at a more global level and the texture or colour (17) of skin at a more detailed level. Let us illustrate this process for an ambiguous figure so that we can explore how it could illuminate gestalt switch as well as gestalt perception.

Data-driven and Concept-driven Processes in Gestalt Perception

Consider the drawing used by Fischer (18) (see Figure 3). It represents the face of a man or a sitting girl. Depending on what forms are extracted as most salient, a partial interpretation of either the outline or an internal part or some textural element (e.g. the hair) or a combination of some of these activates a semantic network. This is a system of concepts represented by nodes which are linked by means of labeled, i.e. specific relations. The semantic network for face contains as nodes *face, eyes, nose, mouth, ears, hair*, etc., and these are linked in terms of part-whole relationships. Eyes are part of a face, so are ears, nose, etc . . . The semantic network for *mouth* contains as parts *lips, teeth, tongue* . . . . In short, the semantic representation contains, in terms of a hierarchical tree, the conceptual decomposition which we mention while discussing the empiricist model of perception. One or more particular forms activate some of the nodes at some level in this hierarchy and further exploration is then guided by upward and downward exploration within that conceptual hierarchy. In the older empiricist language it could be phrased as follows: When a particular form suggest the idea of a mouth, this idea, being part of a network of knowledge elements, suggests the idea of a face as a superordinated unit and the idea of teeth as a subordinated unit. Since each of these ideas is supposed to have some pictorial form(s) associated with it, in addition to its links with other nodes, ideas or concepts, it can provide concrete suggestions for perceptual search (19). When I have tentatively interpreted some forms as eyes, nose and mouth, an elliptical shape of a certain size should indicate the boundary of a head and I may actively look for it. Four types of subprocesses combine in this activity. Some abstract perceptual forms in certain configurations trigger conceptual nodes somewhere in a semantic network. They might be called *data driven*, since they originate, in principle, in the data, events in the outside world. Within the conceptual system of the semantic network, explorative processes might develop from part to whole, i.e. *bottom up* or from whole to part, i.e. *top down*. Finally, the nodes thus activated generate mental image like elements, *concept driven* production of forms that orient search for additional data in a precise and specific way. The final "percept" contains both concept driven (knowledge based) entities and data driven entities so that knowledge and data interlock and constitute together a "solid" object.

There are several intriguing aspects to this new way of looking at perception. One is that it dissolves the old riddle of Gestalt psychology that "the whole is more than the sum of the parts". That riddle can only arise within an approach that requires the seeing of parts in order to see a whole. In the new approach, the whole is accessible to perception independently of the perception of parts. One can discriminate the elliptical outline of a head without recognizing some smaller entities as parts of a face. In this sense, the whole is indeed more than the sum of its parts because the whole is an additional part with its own perceptual representation. Confusion arises from conflating two senses of "whole", a perceptual sense and a conceptual sense. The second sense of "whole" is the transversal connection between several

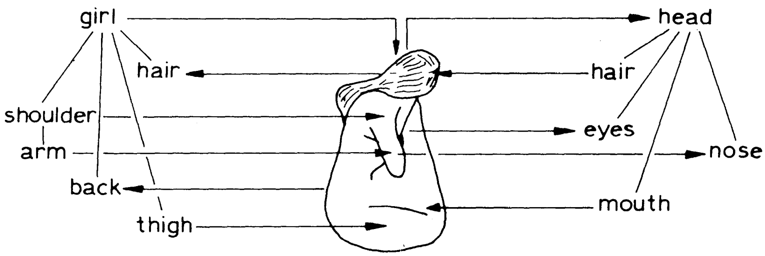

Fig. 3. Fischer's man-girl figure.
Triggered by data-driven identification of either a global shape and/or some internal edge(s), contour(s) or texture(s), a conceptual framework is activated that allows for the generation of concept driven expectations by means of bottom up and top down conceptual processes. Arrows pointing from figure to labels are meant to give examples of data-driven linkings between forms and concepts. Arrows pointing from the label to the figure indicate concept driven links whereby specific 'figural' expectations are derived from an activated conceptual node.

levels of analysis which is achieved, as we have illustrated, by means of a conceptual network. Seeing the whole in that second sense comes down to *knowing* the part-whole connections between perceptual forms at various levels of analysis (at various visual angles, various levels of resolution).

It should be clear that we have now sketched an *interactive* theory of perception which is superior to the collision model suggested by the cognitive approach. Both expectations and data can be expressed in the same language of forms so that an object of perception is built up of entities that dovetail rather than collide. In its layered structure, data driven and concept driven forms combine into a whole held together by a conceptual hierarchy of functional relationships. It might seem far-fetched to invoke this conceptual knowledge as 'theory' penetrating perception in the case of our daily objects and the simple drawings which compose the ambiguous figures. However, in its application to genuine cases of scientific observation, such an interpretation of the new scheme does not seem improper. In an analysis of Harvey's discovery of the circulation of the blood we will try to indicate how it could apply to both cases of minute description and brilliantly wide vision.

Galen and Harvey, Two Keen Observers

In line with the positivist image of science, Harvey's discovery of the circulation of the blood (1628) is usually depicted as one of the most typical victories of the scientific method over medieval speculation (20). It is presented as if all that was needed was someone who looked more carefully and systematically at the facts than at the books of predecessors in order to disclose the truth. However, when reading Galen (129–199), the creator of the rival model of the vascular system for more than fourteen centuries, one is confronted with an author who is a strong defender of careful observation. In refering to his emphasis on sense perception in science, N. W. Gilbert calls Galen's doctrine of science "an astonishingly modern doctrine of logical empiricism" (21)! From the pages of Galen's descriptions, one retains the conviction of reading an author with great skill in anatomy and an enormous practical experience. Graubard rightly rejects observational ability as a criterion to distinguish Galen from Harvey and argues for a psychological approach which seeks "to determine how brilliant minds operate" (22), both Galen's and Harvey's.

Another trait, in addition to dedication to observation, which Galen and Harvey have in common, is their need for an adversary position to push off against. For Galen, the opponent is Erasistratus whom he blames for making "rash assertions without observing" (23). Harvey, more careful and understanding that "habit or doctrine once absorbed . . . become second nature" is convinced to surpass Galen. Though both are keen observers, the conceptual scheme of an opponent has apparently been a major device for orientation and direction in a complex area. Obviously the intriguing question is: how can such a scheme that has been instrumental in seeing be overthrown by new observations? Where do the latter come from and how can they upset the scheme?

However, before we consider whether Harvey's discovery can be looked upon as a gestalt switch, we should inquire whether it is legitimate to see Galen's and Harvey's descriptions of the vascular system as related in terms of the duck and the rabbit of our celebrated example.

Angiological Duck and Rabbit

The gist of our argument has been that perception involves the use of perceptual forms selected at various levels of resolution which are combined and hold together by a conceptual network. To illustrate the potential use of this conception for an analysis of observation in science, we should be able to indicate how particular perceptual forms retained from observation at various levels combine with specific conceptual systems to yield the type of integrated view that also typifies the seeing of an object.

Anyone who has ever been obliged to put to practice his anatomical knowledge drawn from books and pictures knows how bewildering reality can be in comparison to the clear and simple schemes of the books. Both Galen's and Harvey's model are attempts to arrive at a clear picture of the complicated system of organs and tubes which we now know as the respiratory and circulatory systems but which to an apprentice anatomist should be comparable to the meaningless patchwork of black and white blotches that characterizes a first confrontation with pictures such as Porter's hidden man or R. C. James' dog (24).

Galen's model is characterized by a distinction between a system for alimentation (the veins) and a system for ventilation (the arteries). The introduction of a ventilation system based on blood – arterial blood – is a feature of Galen's system which distinguishes it from others which considered arteries to be comparable to the trachea filled with air or spirit. He rejects a classification of arteries as windpipes though retains a ventilation function through aerated blood. At various levels, Galen can claim clear perceptual indicators to justify his conceptual distinctions:

– venous blood differs from arterial blood in colour and viscosity; venous blood is blueish red and thick, arterial blood is highly red and thin and vaporous;

– veins differs from arteries; arteries are harder, have a coating differing from the coating of veins and can be up to five times thicker; furthermore arteries are distinguished from veins by their pulsation which Galen considers their prominent feature;

– both systems seem to have their own major organ: the position and the connection of the portal vein with respect to the liver is comparable to the relationship between the aorta and the heart;

– pulsation as a rhythmic alternation of inhalation and evacuation is a feature of both the respiratory system and the arterial system. It is noticed at the level of arteries, the heart, and the lungs and becomes a major organizational principle in Galen's model apparently allowing him to make the connection between the two systems. It is often referred to in terms of the so called *tidal* model with an ebb and flow rhythm.

A major anomaly which Galen struggles at pains to explain away is the structure of pulmonary vessels. In a scheme that considers venous blood as alimentation produced in the liver and distributed through the veins, the arterial structure of the vessel that connects the right ventricle to the lungs (the pulmonary artery) is at odds with the fact that it contains venous blood. The introduction of an arterial vein (pulmonary artery) and a venous artery (pulmonary vein) is the major weakness in the Galenic model.

Obviously, there are many more important aspects to Galen's description but we need not to consider them here. Our only claim is that his model can be seen as a conceptual system which combines perceptual features withheld from the study of some tubular parts of the body at various levels of analysis into a unitary view.

Confronted with the same tangle of tubes, Harvey arrives at another picture. He too can claim clear perceptual indicators to justify his conceptual distinctions:

– venous valves suggest a centripetal rather than a centrifugal blood flow;
– ligatures of the veins show an emptying between the ligature and the heart while in arteries the opposite is true: swelling occurs between the ligature and the heart;
– contrary to Galen's description, the active moment of the heart is the contraction and not the expansion; rather than sucking in blood, the heart propels it away;
– the total quantity of blood is apparently fixed and from the amount pumped away at each contraction of the heart, one has to infer that it moves around in a circle.

Many more ingenious and subtle observations can be found in Harvey's work, but the ones we have retained are among the most important. Notice how again, they specify perceptible attributes at various levels of aggregation: valves as parts of the veins, the level of the vessels, the level of the heart, some perceptually specifiable attributes of the overall system: the total amount of blood in an organism.

Presented in this schematic way, both Harvey's and Galen's model for the vascular system qualify as integrated conceptual entities which relate in a functional way subparts, parts and wholes which have each at their own level, perceptually accessible forms. In that sense, they might seem to relate as the rabbit and duck of the famous ambiguous figure. However, such schematized presentations are to scientific observation what pictures are to "real" perception. And as Gibson indicates, we should beware of taking the reading of pictures as representative of the observation of a real scene or object. Even under poor perceptual conditions few people will confuse real rabbits with real ducks. In contrast to cartoon-type drawings, real objects allow for a "closer look" which means that additional levels of analysis are accessible and can be added or interposed. Do such "closer looks" account for the dynamics of one scheme into another?

Origin of Gestalt Switch: New Theory or New Data?

A conceptual scheme offers the possibility of seeing unity and coherence in an otherwise puzzling multitude of perceptual forms. In the way we have presented them, both Galen's and Harvey's allow for the interactive kind of perceptual process we dealt with above. However, when dealing with science the challenge apparently is to explain either how observations give rise to *new* expectations or how expectations give rise to *new* observations. How and why was the one system abandoned and replaced with the other? The case of Harvey is interesting in that several alternatives have been documented for locating the origin of his discovery ranging from the observation of an apparently minor detail to purely speculative general ideas (25).

It can be argued that first the new idea arose, a concept that had to be elaborated "downward" to the level of observation in disregard of the perceptual attributes used in the accepted scheme. It is indeed obvious that Harvey ignores or minimizes the relevance of some of the observable differences exploited by Galen. He ignores the difference between venous and arterial blood. He argues against emphasizing the difference between arteries and veins: "in many creatures, . . . , a vein does not differ from an artery by the thickness of its coat" (26). Where Galen sees two major organs, the heart and the liver, each governing their own subsystem, Harvey sees but one. He describes the heart as "the first principle of life and the sun of the microcosm, just as the sun deserves equally to be called the heart of the world" (27). One could argue that it is a conviction of this kind, a general idea about the central role of the heart and the unity of the blood, that set off Harvey's revolt against the Galenic view. Such ideas, including the high esteem for circular motion as the main force of the cosmos at large are, according to Pagel, entirely compatible with Harvey's admiration and adherence to Aristotelian notions. Pagel, who has done some of the major studies on Harvey, would consider these as "philosophical, mystical or religious 'side-steps' of otherwise 'sound' scientific workers" and he sees it as the task of the historian "to uncover the internal reason and justification for their presence in the mind of the savant and their organic coherence with his scientific ideas" (28). But if such ideas are at the origin of Harvey's innovation, the problem is not so much whether they are scientific or not. The problem is to see how they can guide observation.

According to Harvey's own account of his discovery as reported to Boyle at some time, it was the observation of the venous valves that made him rethink the whole of the vascular system. Whitteridge (29) has considered this a crucial element for the construction of an interpretation that stresses "observation" rather than "ideas". This could equally be made a nice illustration of another type of "external" (30) factor: a teacher-pupil relationship. During his stay at the major medical school of his time, the university of Padua, Harvey studied with Fabricius, the discoverer of the venous valves. This biographical element could be a sufficient reason for providing to this particular observation a special and prominent status in Harvey's mind. But again, if this is the spark, what did it set in motion? Why should one develop the need to overturn the Galenic system by scrutinizing the venous valves?

It should be clear that as long as it is phrased in terms of *either* ideas *or* observations which set a discovery on its way, the question remains puzzling. Observations and concepts interact all the time and cannot be taken apart, neither in the course of scientific investigation nor in the case of simple object perception. Pagel is well aware of this in his general appraisal of possible origins for Harvey's discovery:

> . . . we cannot separate the single 'spark', in his case the venous valves, from the tangle of ideas which seem indissolubly bound up with it and form the complex background of his discovery. Nor would it be easy to say which came first: idea or observation, or even philosophy or observation, . . . there is support for the view that indeed the idea came first. Harvey had been a staunch Aristotelian all the time – by up-bringing as well as by inclination. Perhaps this and all that it had taught him about the heart and the blood *influenced the way in which he looked upon the venous valves* (30) (italics added).

This is the challenge and this is what the new model of perception should achieve: to determine how general ideas influence the way one looks at specific objects.

In a later treatment of the subject, Pagel unambiguously opts for the primacy of the *idea* explicitly stating "that the discovery was at first an *idea* which called for the provision of evidence in order to be proved and demonstrated rather than a conclusion drawn from evidence already available 'en masse'" (32). In his conclusions, he uses the term "a 'hunch' or idea that formed the challenge to produce such evidence *de novo*" (33).

Besides some indirect support for such confusing notions as that ideas are general and of a wide range while observations are small and needed in great number before they count, these statements do not explain very much. Where does a hunch come from? Are no observations involved in its construction? And once it has been installed, how does it control the search for evidence, how is it transformed into specific expectations? Somewhat surprisingly, in the same monograph (34) Pagel seems to approve of Bylebyl's *two-step-model* although the latter seems to allow for a more subtle analysis of the commerce between observation and ideas.

Gestalt Switch in Two Steps

According to Bylebyl (35), Harvey's celebrated monograph *An Anatomical Disputation concerning the Movement of the Heart and Blood in Living Creatures* (1628) has been written in two quite distinct phases. The part on the motion of the heart and arteries should be considered as written years before the part on the movement of the blood. Harvey first developed his theory on the movements of the heart as an extension of the old view, i.e. an augmented Galenic scheme to which Harvey, in a sense, thought to contribute by making local corrections and adding detail. The conspicious "detail" he thereby noticed was the substantial amounts of blood necessarily transmitted by the heart within even relatively short periods of time. Once it was abundantly clear for him that the blood *moves*, that it moves fast and massively, this movement became something Harvey felt he had to account for. The discovery of the *movement* of the blood as a consequence of the movement of the heart is *phase one*, not necessarily incompatible with the older scheme though generating very serious questions. *Phase two* is the disclosure of *circulation*, the discovery that the blood moves in a circle, a revolutionary new idea. The crucial step in arriving at this idea is apparently a conceptual jump. Here the Bylebyl-model can be connected to Pagel's who emphasizes Harvey's sympathies for Aristotelian concepts in which circular movement is considered the ideal type of movement containing both preservation and change.

On a global scale, the two-step-model of Bylebyl is compatible with the gestalt switch associated with ambiguous figures. It would however oversimplify issues to look upon the first stage as observational, largely "data-driven" and the second stage as theoretical or "concept-driven". On the level of details, the interactive mode of perception seems to apply in stage one in the same way as in stage two. Bylebyl's account does not separate the "data" from the "ideas" in any specific way. What are we to conclude from this?

Conclusions

Unlike the simple line-drawings of tricky figures, which offer a very restricted number of levels of analysis, the objects of observation in anatomy offer opportunities for analyses at many levels. Between Galen and Harvey, several discoveries have been made which modified and corrected the Galenic view substantially. Nevertheless, although these discoveries resulted in important local revisions, they have not led to a global reorganization of the view on the vascular system. It required Harvey to reconsider the consequences of the movements of the heart, in order to arrive at the idea of a revolutionary reorganization at the global level. Abstracting from the preparatory discoveries by others, Bylebyl's two-step-model for Harvey's discovery corresponds to the two-step-model for gestalt switch exemplified in the celebrated figures. Observations at some particular levels suggest a local reinterpretation which upsets the conceptual system in such a way that global reorganization results from it.

It would however be totally inappropriate to consider local reinterpretations as purely observational while taking the global reorganization as purely theoretical. The observations expressing Harvey's understanding of the heart are of the same nature as those expressing his discovery of circulation. In each case we find the same integrative and interactive perceptual process whereby a perceived object is constructed as an amalgam of forms whose coherence depends on a conceptual network that specifies their relationships. The major difference is that the first one remains at an intermediate level within the conceptual network while the second one expresses a reorganization of the network at top-level. But still the basic question remains, how do new observations arise in the old schemes?

Only one answer seems plausible for confronting this question: new observations are imported from other, apparently unrelated areas. On the level of the global reorganization, we have already mentioned the Aristotelian concepts on the perfection of circular movement. That this is an "imported" conceptual network can be argued on the basis of Pagel's remark that Harvey should be considered "a kind of split mind" or "a dweller in two worlds" (36). One world is an Aristotelian one, the other is the world of modern anatomy. However, also on the intermediate level and the level of detail "external" schemes intrude and lead into less spectacular but not less important changes. As we have indicated, the heart in the system of Galen is a different object form the heart in the system of Harvey. In Galen it is like bellows, drawing in blood in a way similar to and coupled to the way in which the lungs draw in air. In Harvey, it is a pump-type organ which actively propels blood through the vascular system. As far as the pump-analogy has influenced Harvey's perception (37) it is equally a scheme imported from yet another conceptual realm. Analogies like this one seem particular apt to express a newly observed relationship between two levels of analysis. Notice that with respect to the central insight of the circle, Harvey points to the inspiring analogy of the vapour-rain-water-cycle. Without exploring whether the analogy is only a way of expressing a newly discovered relationship or also an important instrument in finding it, we should recognize its capacity to function as a vehicle for importing new local conceptual schemes from areas outside the guiding conceptual framework. Though, considered that way, new schemes can only enter piecemeal, they can enter, in principle, at many levels. This implies an unexpected openness of scientific theories.

The major shift brought about by recognizing the hierarchical dimension in perception of simple objects is the abolishment of the notion of "solid soil of observation". Perceptual entities can penetrate conceptual pyramids at many levels. It seems indicated to think in terms of a continuum between vision as encountered in the perception of objects and creative vision as expressed in scientific innovations. With the removal of a "solid soil", the metaphor of founding scientific theories on the rock bottom of observation becomes empty. If a new metaphor is needed, the notion of *ventilation* could replace the notion of *foundation*. It would emphasize that observation enters our conceptual edifices at several floors simultaneously. Though our analysis might seem predominantly involved with problems in psychology of science, it is not without consequences for sociology of science issues.

The openness for observations at many levels means also an openness at these levels for fragments of conceptual schemes from foreign areas, whether from other areas of science, or technology, or down to earth daily routines. As we have seen in studies on Harvey, his new vision on the global system might stem from his Aristotelian background, his view on the heart couples to a technological device such as a pump and the valves in the veins are seen as flood-gates. Even casual observation of a meaningless action such as blowing in a glove can harbour the seed of innovation as is manifest from Harvey's observation of the pulse in arteries. These are all observations that originate in schemes that are *external* to the dominating conceptual network of the scientific discipline. They constitute so many apparently innocent but nevertheless efficient entries for letting in the *new*.

Illustrating the creeping way in which new observations penetrate into the old conceptual network, the scheme we have explored allows a new analysis of the intertwining of (partly redefined) internal and external factors. Obviously, many questions remain. One of the most intriguing ones is why a scientist is looking for the new. Why would an observer with a Galenic outlook on the vascular system feel inclined to improve upon the scheme? Why first extend it and later on reorganize it? From where this unsatisfiable need to improve upon what one has? Though this is a most basic question pertaining to the equilibruim and the dynamics of conceptual systems, it is beyond the scope of this analysis on the relationship between theory and data (38).

Notes and References

1. M. J. Mulkay, *Science and the Sociology of Knowledge*, Allen and Unwin, London, 1979, pp. 27–49.
2. A. Shimony, 'Is Observation Theory-Laden? A Problem in Naturalistic Epistemology', in R. G. Colodny (ed.), *Logic, Laws and Life*, University of Pittsburgh Press, Pittsburgh, 1977.

3. H. Feigl, 'The 'Orthodox' View of Theories: Remarks in Defense as well as Critique', in Radner and Winokur, *Minnesota Studies in the Philosophy of Science, Vol. IV*, Univ. of Minnesota Press, Minneapolis, 1970.
4. Einstein quoted in W. Heisenberg, *Physics and Beyond*, Allen and Unwin, London, 1971, p. 63.
5. L. A. Necker, 'Observations on an apparent change of position in a drawing or engraved figure of a crystal, an optical phenomena which occurs on viewing a figure of a crystal or geometrical solid', *Philosophical Magagazine* **1**, 329–337 (1832). Excerpt in W. N. Dember, *Visual Perception: The Nineteenth Century*, Wiley, New York, 1964, pp. 78–80.
6. T. S. Kuhn, *The Structure of Scientific Revolutions*, University of Chicago Press, Chicago, 1962, p. 110.
7. E. H. Gombrich, *Art an Illusion: A Study in the Psychology of Pictorial Representation*, Phaidon, London, 1977[5].
8. *ibid.*, p. 198.
9. F. C. Bartlett, *Remembering: A Study in Experimental and Social Psychology*, Cambridge Univ. Press, Cambridge, 1967[5].
10. M. Minsky, 'A Framework for Representing Knowledge'. In P. H. Winston (ed.), *The Psychology of Computer Vision*, McGraw-Hill, New York, 1975, pp. 211–277.
11. R. W. Leeper, 'A Study of a Neglected Portion of the Field of Learning – the Development of Sensory Organization', *Journal Genetic Psychology* **46**, 41–75 (1935).
12. J. J. Gibson, *The Perception of the Visual World*, Houghton Mifflin, Boston, 1950.
13. J. J. Gibson, *The Ecological Approach to Visual Perception*, Houghton Mifflin, Boston, 1979.
14. B. S. Lipkin and A. Rosenfeld (eds.), *Picture Processing and Psychopictorics*, Academic Press, New York, 1970.
15. S. E. Palmer, 'Visual Perception and Knowledge: Notes on a Modal of Sensory-cognitive Interaction', in D. A. Norman and D. E. Rumelhart, *et al., Explorations in Cognition*, Freeman, San Francisco, 1975.
16. S. E. Palmer, 'Hierarchical Structure in Perceptual Representation', *Cognitive Psychology* 9, 441–474 (1977).
17. In this new approach, the recurrent element at each level is *shape*: contour as shape of the whole, internal contours as shapes of parts, texture as revealing the shape of micro-parts. Colour fits into this hierarchy too when considered a limit case of texture.
18. G. H. Fischer, 'Ambiguity of Form: Old and New', *Perception and Psychophysics* **4**, 189–192 (1968).
19. With respect to systems for the representation of knowledge, the idea is to have links to pictorial elements at several conceptual levels and nodes in the semantic network, somewhat along the line suggested by A. L. Glass, K. J. Holyoak, *et al., Cognition*, Addison-Wesley, Reading, 1979, p. 21. However, where they put complete pictures into the semantic network, we would emphasize more simple and elementary shapes. It is a central theme of R. Arnheim, *Visual Thinking*, University of California Press, Berkeley, 1971[3], that visual representations – pictures – are made up by means of a restricted number of elementary shapes: circles, ovals, straight lines, arches, angles, rectangles. Following Pestallozzi, he considers these

elements as constituting the *alphabet* of the *shape* of objects. Pictures are like words or sentences written in circles, rectangles and arches. Ignoring aspects of size, it is indeed surprising to realize how the great variety of shapes that we know can be reconstructed with so few elements. And when size is taken into account, it is surprising to realize how flexible the system is. A few dashes or dots within a circle make up a face. Perception can cope with a wide variety of distortions: tilted ovals, alongated ones, flattened ones . . . . They are all handled as different tokens of the same type, just as the widely differing handwritten forms of a character represent one single type. Apparently, there are standard perceptual representations constructed out of a limited number of pictorial elements depicting the structure of objects along two or more levels of a conceptual hierarchy.

20. See, for example, M. Kirchner, *William Harveys Verdienste um die Entdeckung des Blutkreislaufs*, Schade, Berlin, 1878, p. 6.

> Mit Harvey begann eine neue Art zu forschen. An Stelle aprioristischer Speculation trat Beobachtung und Experiment, an Stelle blindgläubiger Teleologie die mechanische Erklärung.

21. N. W. Gilbert, 'Galen'. In P. Edwards, *The Encyclopedia of Philosophy*, Vol. 3, Macmillan, New York, 1972^2, pp. 261–262.
22. M. Graubard, *Circulation and Respiration: The Evolution of an Idea*, Harcourt, Brace and World, New York, 1964, p. 56.
23. If not otherwise indicated, quotations from Galen stem from the selections in Graubard, *op. cit.*
24. P. B. Porter, 'Another Puzzle Picture', *American Journal of Psychology* 67, 550–551 (1954). The photograph by R. C. James can be found in P. H. Lindsay and D. A. Norman, *Human Information Processing. An Introduction to Psychology*, Academic Press, New York, 1977^2, p. 12.
25. As a major source with respect to Harvey's discovery and the various theories offered to explain it, we have used W. Pagel, *William Harvey's Biological Ideas: Selected Aspects and Historical Background*, Karger, Basel, 1967, W. Pagel, *New Light on William Harvey*, Karger, Basel, 1976, J. J. Bylebyl (ed.), *William Harvey and His Age*. John Hopkins University Press, Baltimore, 1979.
26. W. Harvey, *An Anatomical Disputation concerning the Movement of the Heart and Blood in Living Creatures*, trans. with introduction and notes by Gweneth Whitteridge, Blackwell, Oxford, 1976, p. 76.
27. *Ibid.*, p. 76.
28. Pagel, *op. cit.*, 1967, p. 82.
29. G. Whitteridge, in W. Harvey, *op. cit.*, introd., xxvii–li.
30. The first type of external factors mentioned are what Pagel calls "philosophical, mystical or religious 'side-steps'".
31. Pagel, *op. cit.*, 1967, 210.
32. Pagel, *New Light on William Harvey*, Karger, Basel, 1976, p. 5.
33. Pagel, *op. cit.*, 1976, p. 172.
34. Pagel, *op. cit.*, 1976.
35. With respect to Bylebyl's theory, see Bylebyl, 'The growth of Harvey's De Motu Cordis', *Bull. Hist. Med* 47, 427–470 (1973). Also Bylebyl, 'William Harvey'. In Gillespie (ed.), *Dictionary of Scientific Biography, Vol. IV*, 1973, pp. 150–162,

and Bylebyl, 'The medical side of Harvey's discovery: the normal and the abnormal', in Bylebyl (ed.), *op. cit.*, 1979, pp. 28–102.
36. Pagel, *op. cit.*, 1976, p. 1.
37. The importance of the scheme of "pump" in Harvey's discovery cannot be considered as established. According to Pagel, the reference made to it by Harvey "occurs more as an aside than as an idea of principal importance", Pagel, *William Harvey's Biological Ideas*, Karger, Basel, 1967, p. 80.
38. Parts of this paper have been presented at the 'International Conference on Knowledge and Representation' held at NIAS (Netherlands Institute for Advanced Studies) Wassenaar, Netherlands, March 8–10, 1979 and at the conference on 'Social Process of Scientific Investigation' held at ZIF (Zentrum für Interdisziplinäre Forschung), Universität Bielefeld, June 17–19, 1979.

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