Autonomous Organization in Perception and Motor Control

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It is argued that for theoretical and empirical reasons an entirely Empiricist account for perception and action is not possible. This is related to results on the necessity of hidden layers in connectionist models of cognition. For paradigmatic examples in space perception and motor behavior it is investigated what processes can account for the apparent order in these domains. A general tendency towards stability is identified but, for instance, the phenomena of apparent depth in plane drawings or multistability reveal that different kinds or points of stability may compete. The finally achieved stable percept usually depends on symmetry breaking. Similar phenomena can be found in motor behavior where singularities play a similarly decisive role. Finally, the "cost" of these order producing processes in discussed in terms of veridical representations and learnability.

1. Introduction

In 1911 Henri Bergson stated what he claimed to be a truism, namely, that if our senses and our consciousness had unlimited capacity, then the formation of general concepts and reasoning would not be necessary [1]. From a philosophical point of view it might be interesting to persue the consequences of such a statement but as empirical life scientists we have to start our investigation from the premise that in general sensory and attentional resources of organisms are limited and that therefore organism have to act upon incomplete and fallible data. In order to survive, organisms in their actions have to take into account the constraints of their environment. These constraints, however, are not in *the sensory data* but can only be *perceived* if these data obey a lawful organization, that is, there has to be the formation of order in the perception of the world as the prerequisite for a successful acting in and upon this world.

Philosophy and psychology have suggested a couple of solutions for this problem. The most parsimonious and therefore for experimental sciences most attractive epistemic position is that of Empiricism. Spinoza [2] captures best the Empiricist position as "ordo et connexio idearum idem est ac ordo et connexio rerum" which translates into modern scientific language as "the representation of the outside world follows the same rules as the outside world itself". This

Springer Series in Synergetics, Vol. 45 Synergetics of Cognition
Editor: H. Haken and M. Stadler

taken together with Gassendi's [3] sensualistic position according to which there is nothing in the mind that has not been in the senses before, offers an elegant and straightforward solution to the questions concerning the possibility and content of knowledge. Gassendi claimed furthermore that understanding a process is equivalent to constructing a machine. A direct, if somewhat belated consequence of Gassendi's claim and the epistemological point of view of sensualistic empiricism are the early investigations on neural nets by McCulloch and his co-workers [4] and by Rosenblatt on perceptrons [5]. Their results reveal that sensualistic empiricism implies that knowledge can be modelled by means of nothing but an input and an output layer plus associative connections between the nodes and the layers.

Minsky & Papert [6] have shown that such a model is in principle incomplete because for instance the 'exclusive or' is impossible in it. Modern network models have solved this problem by implementing 'hidden layers', that is, by embellishing the structure. This is reminiscent of Leibniz' [7] critical appraisal of Gassendi's position which has to be amended according to Leibniz because the mind itself is in mind, that is, the internal representation depends not only on the rules of external world but also on the structure of its medium, namely the mind. The critical epistemological problem for the life sciences arising from this situation is to make as few a assumptions as possible about the structure of the mind but enough to account for the phenomena observable in animal and human perception and action. One central phenomenon is the inherent order and organization in perceiving and acting.

Koffka [8] has made this point very suggestively "...we accept order as a real characteristic, but we need no special agent to produce it, since order is a consequence of organization, and organization is the result of natural forces". How the order in perceiving and acting can emerge without an external agent has - at least in principle - been demonstrated on a synergetic computer as suggested by Haken and his coworkers [9].

In general, autonomous organization depends on the ability of systems, including organisms to settle at points of minimal stress or maximal stability. Koffka's epistemological position according to which only such perceptual and behavioral processes persist that have survival value for the organism in question, can therefore be consequently re-pharased as: *perceptual processes tuned to the detection of stable or quasi-stable states in the world and behavioral processes making use of these stabilities allow organisms to interact lawfully with the world and thereby improve the organism's chances to survive.* For this reason behavioral sciences are interested in the conditions for stability, in its consequences for the behavior, and in the processes that happen when an organism changes from one stable state into another. In the following, two domains of psychology are analyzed that exhibit these problems in a paradigmatic form: (i) perceiving tri-dimensional space from bi-dimensional displays and (ii) learning and optimizing a motor skill without instruction. One prototypical example for the first domain is the Necker-cube, a line drawing that gives rise to a pair of tri-dimensional alternating percepts. The second domain can be exemplified by the evolution of the individual script during life time, where not only ideosyncratic forms of letters evolve but, specified for situations, an optimal trade-off is found between the fluency of the motor process and the legibility of the script [10].

In both domains stability refers to minima in an energy landscape; if there is more than one minimum, multistability results, as in the Necker-cube example, where the rate of alternating between the percepts is closely related to a generalized distance between the respective minimal positions in an activation network [11]. In the motor domain the swinging of arms in relation to the leg movements in walking is an example of bi-stability: Both, swinging in the same phase or swinging with a 180° shift is stable, however, if the walking speed is increased, swinging with a 180° shift becomes more and more probable. This highlights the problem that stability of percepts and actions is not fixed but depends on external factors as speeding up/slowing down or adding/removing perturbations. Outside of these regions of stability there is either noise, that is, percepts and actions can only be described in stochastic terms, or chaos, that is, a multitude of qualitatively different percepts or actions is possible but since minute and indiscriminable differences in the initial conditions are responsible for the resulting effects these are essentially unpredictable. The following examples exhibit either stability or situations where either the transition from one kind of stability to another follows comparatively simple rules or where the manipulation of a sigle parameter produces stochastic or fast alternating burst-like phenomena.

2. The Role of Stability in Perceiving 3-D Space from Pictures

A straightforward and intuitively convincing account for the ability of humans to perceive depth from flat depictions (e.g. line drawings or photographs) has been given by Gibson [12]: "...there are no differences among people in the basic way of seeing, that is, by means of light, and by way of rectilinear propagation of light." Therefore, he concludes, linear perspective in drawing is not a convention. One consequence of this view is that any line drawing (and, a fortiori, any photograph) in accordance with linear perspective should induce a perception of apparent depth much faster than a line drawing violating the rules of linear projective geometry. However, if one presents subjects different cube drawings (Figure 1 a-f), it turns out that the effect is strongest in d, a, e, and c (in decreasing order) and that only rarely any depth effect at all can be found with b and

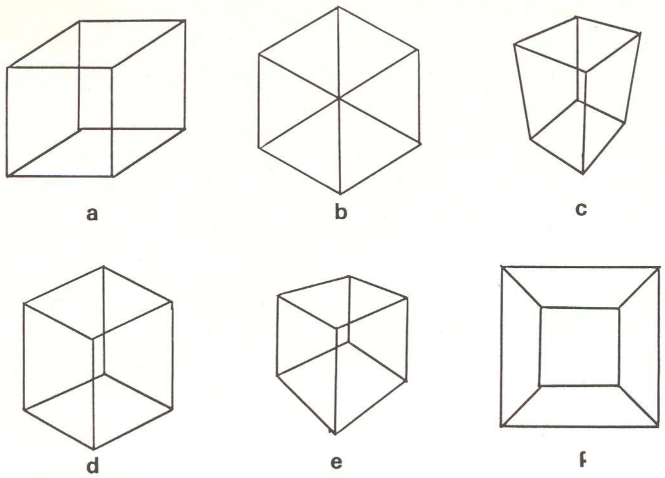

Figure 1 Projections of skeleton cubes; for details see text.

f. This contradicts Gibson's explanation because d is an orthogonal projection without a vanishing point, implying that it is seen from infinite distance, and a is an impossible cube from the point of view of projective geometry. That is, the two drawings producing the fastest impression of tri-dimensionality do not comply with any real world projections people have been able to observe. In contrast, the drawings with 2 or 3 (e; c) vanishing points need more time to induce a comparable effect. However, the line of puzzling results does not stop here: Drawing b is entirely equivalent to d but does not induce depth and drawing f is a possible cube projection with a central vanishing point but is seen as a flat picture frame. In order to account for these anomalities of depth perception Gibson [13] has revised his definition of a veridical picture: "an array of persisting invariants of structure that are nameless and formless." Invariants might be on the one hand those of projective geometry and on the other hand those of an occlusion topology. In the following, I want to illustrate with the help of some illustrations from the history of perspective visual art that the impression of tri-dimensionality and the veridical depiction of spatial scenes is induced by perceptual processes that 'restore' stability from less stable configurations and thereby induce depth. The Arabian tile pattern in Figure 2a gives after a relative short inspection time the compelling impression of depth. Instead of a symmetric pattern that can be algebraically described as a symmetry plane group with mirrors, glides and reflections of 120^o turns, one perceives a couple of cubes inclined with 45^o against the fronto-parallel plane. The reason why a perfectly symmetric plane, from an algebraic point of a view, pattern gives rise to an tri-dimensional percept is the fact that symmetry alone does not constitute a stable configuration (for details see [14]). What is necessary in addition is convexity which is violated in the plane but not in three dimensions, where

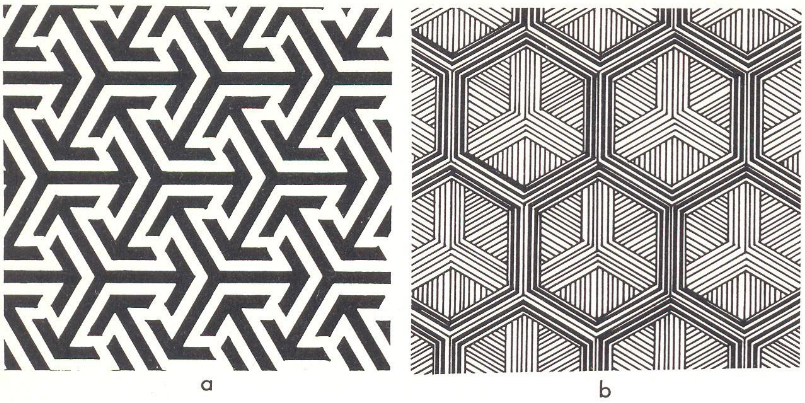

Figure 2 Two tile patterns belonging to the same symmetry group; (a) Arabian (b) Chinese

perfectly convex cubes occlude each other. Figure 2b is algebraically equivalent to 2a, but does not or only very slighly induce tri-dimensionality because it consists of convex parts.

However, even the importance of symmetry for stable configurations has to be specified further. For the case of bi-lateral symmetry Leonardo da Vinci was the first to observe that a vertical axis of symmetry gives rise to a much stronger impression of order and harmony than a horizontal axis. Mach [15] had attributed this effect to the anatomy of the visual brain with two hemispheres but the results of Zimmer [16] reveal that the frame of reference during the inspection of the pattern is decisive. The normal frame of reference for spatial perception is given by the pairs up/down, right/left and forward/aft. From this frame of reference stems the apparent importance of rectangularity in symmetry perception. The Chinese ceramic pattern in Figure 3a appears flat but if we use 60° turns instead of 90° we get from the same elements (3b) a Japanese kimono design (3c) that appears to be tilted in space. In this design all corresponding angles are either 60° or 120°.

If we now compare the conditions under which algebraically or geometrically equivalent pattern give or give not rise to apparent depth there can be observed 3 principles: tri-dimensionality is due to (i) symmetry breaking (Figure 1d in contrast to 1b or in contrast to 1f, 1c and e), (ii) violation of convexity (2a in contrast to 2b), and (iii) systematic depatures of angles from rectangularity (3c in contrast to 3a).

It has been argued that perceiving depth from flat drawings is determined by the cultural and environmental influences of our 'carpentered' world. However, experimental studies of visual illusions in different cultures with and without the preponderance of rectangular constructions have revealed that for instance "illusions" attributable to the reconstruction of rectangularity are omnipresent, but that on top of this apparently general process of restoring a most stable

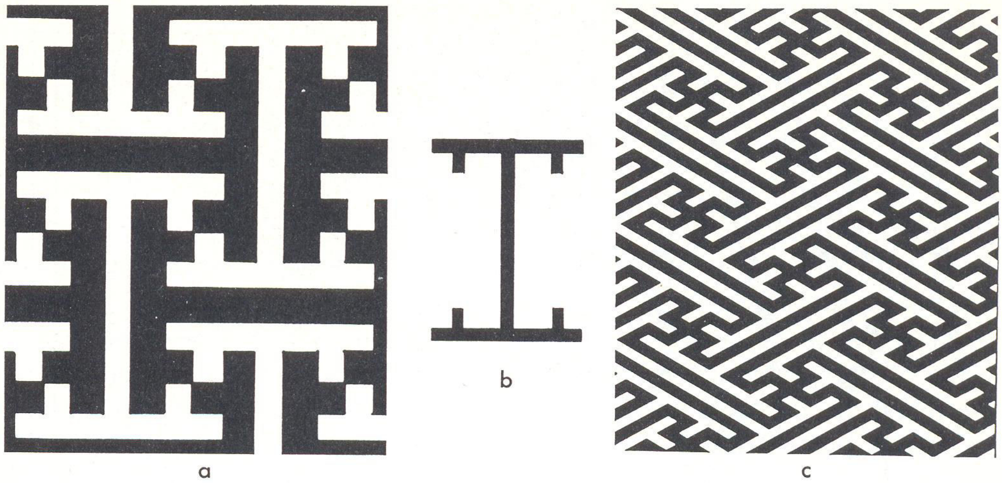

Figure 3 Two symmetric patterns produced from the same elementary form (b); (a) a Chinese ceramic pattern, (c) a Japanese pattern for a Kinomo

configuration there are additional cultural influences on the pictorial literacy for depth perception like the color shift or 'blue-perspective' etc.

However, the importance of this concepts of stability is not confined to the phenomenon of apparent depth. The tri-dimensional form of maximal stability is the cube aligned to the axes of the frame of reference, it can be regarded as a form of minimal stress, a generalized soap bubble. This most stable form plays a decisive role in space perception because it leads to unequivocal percepts from displays that might be generated from a multitude of spatial construction: What is perceived, however, is not a multitude of constructions but the one construction complying best with the stability constraints. La Gournerie [17]has illustrated this in his tract on perspective. Figure 4 shows the interior of a Gothic cathedral and how this view can be generated from buildings with different ground plans. The trompe d'oeil architecture has played with this fact and used it in order to come up with stunning effects; a good example is the doorway of Palazzo Spada in Rom.

However, there is more to learn from the art of drawing on the formation of order in visual perception. The theory of projective geometry and the practical devices for drawing perspectively developed among others by Alberti in *de pictura* (about 1446) and by Dürer in *Unterweysung der Messung mit Zirckel und richtscheyt* (1525) has had an enormous influence on the development of Renaissance art, but from the point of view of space perception there is the question of interest if the pictures giving the impression of depicting the forms and the space just right are the same that obey the rules of projective geometry best. A comparison of Dürer's window (Figure 5a), what the artist roughly saw (Figure 5b), and what Dürer actually has drawn (Figure 5c) gives immediately

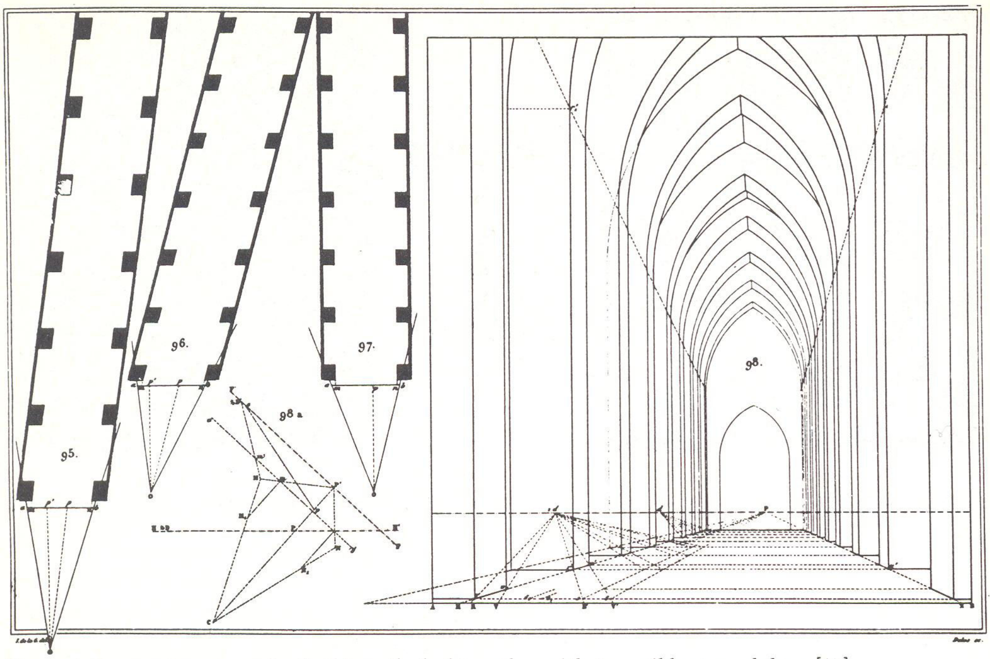

Figure 4 Perspective view of a Gothic cathedral together with 3 possible groundplans [17]

an idea how the picture projected on the window had to be transformed in order to look right. The transformations Dürer made are those that preserve at the same time size and form constancy, that is, for instance, an arm has 3/4 of the length of a leg regardless of the projective distortion and a face exhibits certain relations between mouth, nose, and eyes even if, viewed from an acute angle, the tip of the nose seems to be higher than the eyebrows. Von Allesch [18] was one of the first to conclude that the size constancy he observed in his experiments with monkeys contradicts projective geometry and that therefore the perceptual space is not euclidean. Insofar Gibson's first assumption about the regularities underlying the drawing of a correct picture of space is incorrect. In accordance with Gibson's later view of abstract invariances producing the effect of apparent depth, non-euclidean geometries for the perceptual space have been suggested [19]. For simple configurations of light points in the dark, the subjective distances can best be accounted for by a Riemannian geometry. One persisting problem for this approach is that the curvature of the space is only constant for a given complexity of the spatial situation. Suppes [20] has integrated these results by claiming that only situations of low complexity are non-euclidean but that complex spatial displays are euclidean. Shepard expanded this view by stating that the phenomenal space of a naturalistic environment is locally euclidean but beyond that a high dimensional configuration space, that is, a manifold [21]. A closer inspection of artworks that depict the experienced spatial configuration better than a photograph will show that these pictures form irregular geometries as postulated by Shepard.

The discrepancy between the original perception of a scene and what is shown on a photograph is a common-place experience. For example, more than 70 % of Piranesi's *Vedute di Roma* are rated by subjects as more veridical than photographs showing the same locations and taken from the same positions as Piranesi's etchings. Therefore, Piranesi's systematic method of transforming the picture according to projective geometry into his final etchings can tell us something about the irregular geometry of space perception. His method can be illustrated best with the view of the Forum, the *Campo Vaccino* (Figure 6), where most of the angles and distances in the etching can be compared to those obtained by linear projection because his point of view is known and practically all buildings are still in site. If the discrepancies between the correct and the distorted measures are clustered so that similarly transformed objects are classified together, there result four distinguishable regions: The foreground area (the people and fountain in front) where due to size constancy no fore-shortening happens, the close mid area (the 3 collumns of the Castor and Pollux temple and the church at the left) where foreshortening is less than it should be, the far mid area (houses) which is in accordance with the laws of perspective, and the far away area (the church on top of the mountain) where the height of the belltowers is increased by a factor of 2. That these areas of distinguishable geometric properties are not a matter of artistic convention can be seen from the fact, that for artists concerned about perspective as much as Dürer and Piranesi the transition from one area to the next poses problems. The left leg of the nude in Figure 5c was closest to the contraption for perspective drawing (Figure 5a), that is, in the area of size constancy, whereas the other parts of the body were further removed. The transition of the leg to the rest of the body therefore looks somewhat distorted. Even more clear is the case in Piranesi's veduta of the Colosseum (Figure 7a). The frontal part (the close mid area), where a compromise between size constancy and foreshortening has been found, and the side part of the Colosseum (the far mid-area), where the laws of perspective hold, do not fit together and the resulting impression of the form of the building is more that of a horseshoe than that of an ellipsis as it should be (Figure 7b).

A special feature of Piranesi's *Vedute* that discrimates his treatment of spatial scenes from that of most of his fore-runners (e.g. Pannini's *Vedute dal vero*) or his pupils (e.g. Rossini) is the accentuation of landmark objects close to the horizon (e.g. the bell towers of S. Maria Maggiore in Figure 6). Experiments have shown that for the impression of spatial veridicality in drawings landmark objects but not the surrounding landscape have to be exaggerated in height. Therefore, even for this region no coherent geometry (e.g. cylindrical projection) can be defined because the distribution of the observer's attention determines

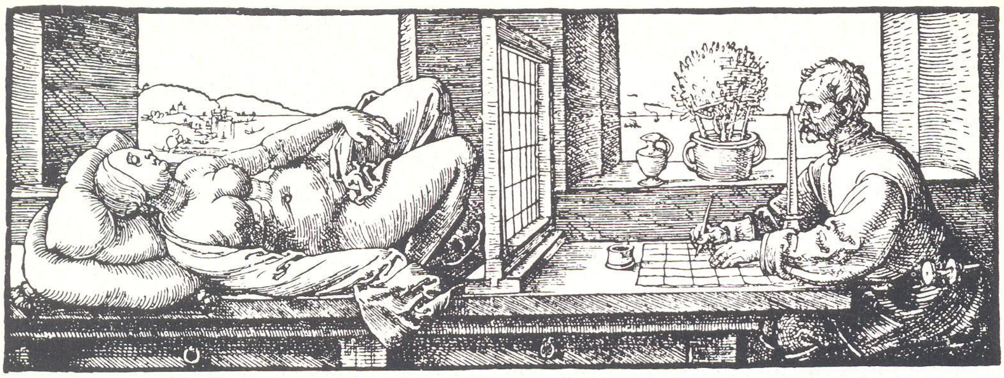

Figure 5a

Figure 5b

c

Figure 5 (a) The Dürer window (side view), (b) the view through the window, (c) drawing of a reclining nude by A. Dürer

Figure 6 G. Piranesi's Forum Romanum from *Vedute di Roma*

the objects that have to be exaggerated in height. Vice versa, the artist can influence the directing of attention by the accentuation of height. Figure 8a shows a landscape close to Regensburg with the correct size relations, 8b is the drawing most subjects chose as the one depicting best the real scene they had seen immediately before, and the shaded area in 8c gives the differences between 8a and 8b. One can see that the surrounding landscape is identical in

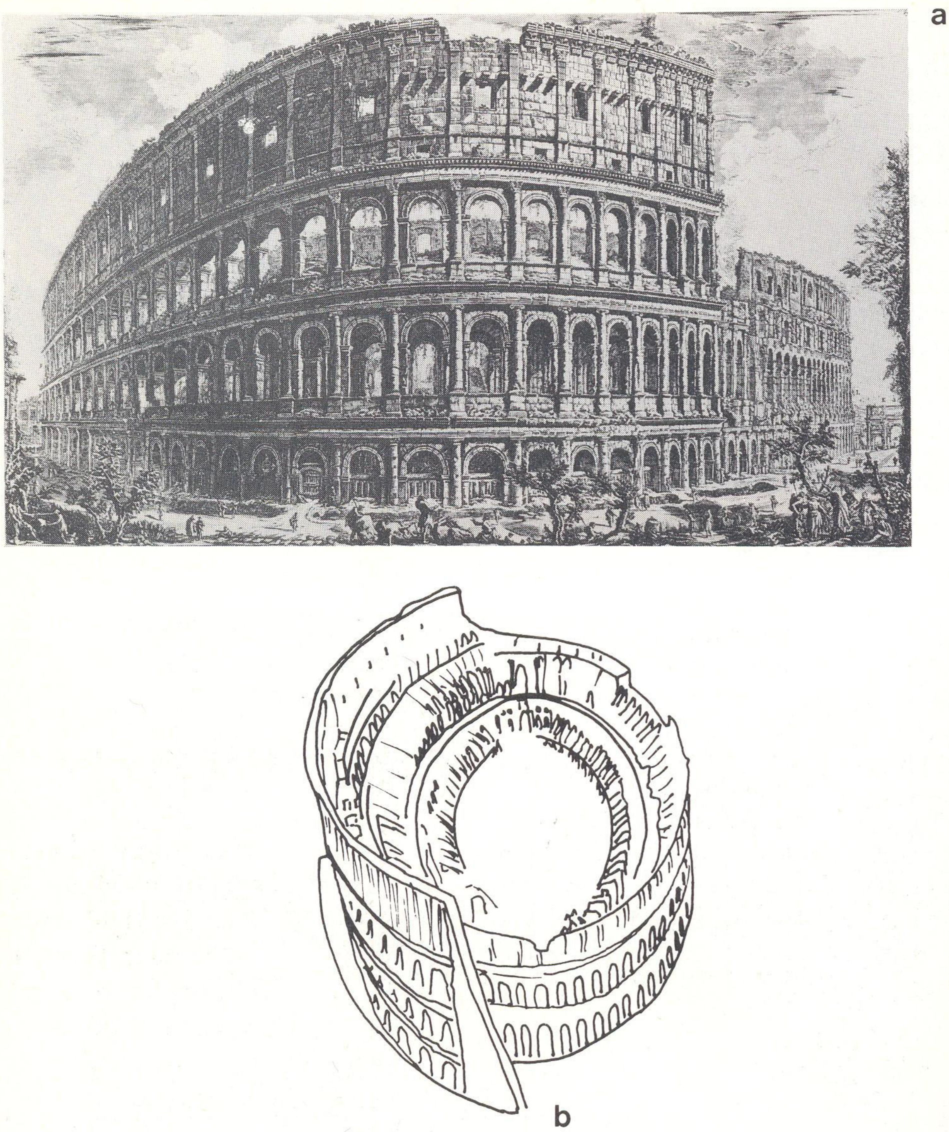

Figure 7 The Colosseum in Rome; (a) etching from Piranesi's *Vedute di Roma (Veduta dell' Anfiteatro Flavio)*, (b) line drawing after an aerial photograph

both pictures except for a tendency towards concavity of the slopes below the castle.

To sum up, the irregular geometry of spatial perception from bi-dimensional drawings does not look irregular anymore if we follow Stadler's suggestion to discriminate between *reality*, the physical world of *things (res)*, and *actuality*, the phenomenal world we *act* upon and which *acts* upon us. The absolute size

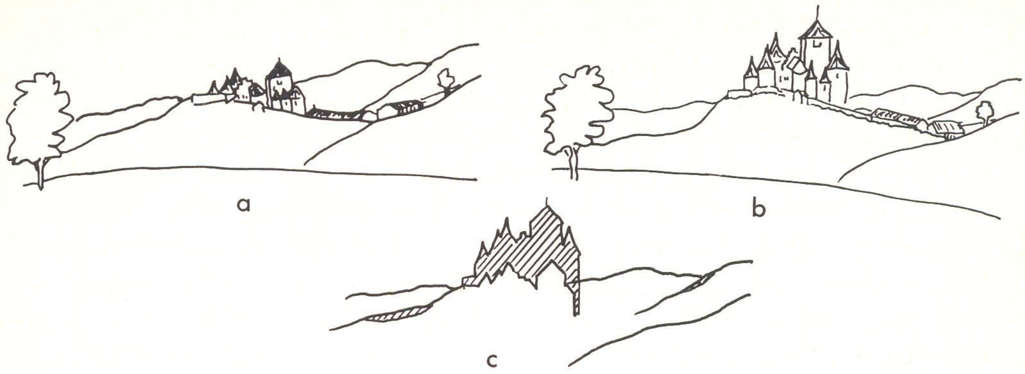

Figure 8 Line drawings of the castle of Wörth; for details see text

constancy of the phenomenal world in grasping distance, the vanishing point geometry where distant movements or of oneself in relation to these things in the world are detected, and the accentuation of landmarks at a distance where the overall orientation of locomotion through a cluttered environment comes from, all serve the improvement of the reality/actuality relation. Shepard has put this interdependency very aptly: "The world appears the way it does, because we are the way we are, and we are the way we are, because we have evolved in a world that is the way it is" [p. 276 22].

3. Unsupervised Motor Learning: Order from Smooth Transitions of Forces

One central problem for the information processing approach to motor behavior [23] is captured best by the joke about the centepede who when asked how he managed the movements of his some 300 feet, said: "Gee, I have to think about it!" and never could walk again. A configuration space for the more than 700 degrees of freedom of the human body appears too complex in order to assume that goal oriented motor behavior might consist in first planning a trajectory through this manifold and second executing the motor acts according to this plan. Since Bernstein's early investigations [24] this problem has troubled movement scientists and many suggestions have been made how to devise motor systems where less parameters have to be controlled [25]. However, the main problem remains that in this framework for controlling motor behavior all kinematically possible trajectories from a defined starting position to an intended final position have to be investigated. This kinematic landscape has then to be transformed into an inverse energy landscape - first kinetic and then potential - for the evaluation of the possible actions.

Such a control process might work for simple positioning tasks, however, already for walking in a naturalistic surrounding the kinematic possibilities increase dramatically and the complexity of the inverse energy landscape be-come insurmountable. As alternative it has been suggested that controlled motor behavior is characterized by the search for local minima of the affordance/effectivity combinations [25]. It has been postulated by Gibson [26] that affordances can be perceived directly by an organism as "what activity a surface layout affords" [27] and thereby tie directly into the effectivities of the organism, that is, the organism's capabilities to act upon its environment [28].

This reduces the complexity but might prevent finding new efficient courses of motor actions (e.g. the Fosbury-flop which was designed by his inventor as the form of high jump where the center of gravity of the body is always below the maximum height to be crossed). Informations-processing theories of motor behavior as well as those influenced by the 'ecological' approach model the underlying anatomy of the moving organism by means of i) oscillators, regarded as practically undamped because in the regulatory process external energy overcomes drag and other damping forces, (ii) point masses, and (iii) rigidity assumptions. This kind of modelling can be found as early as in Leonardo da Vinci's *Notebooks* and in a detailed analysis of animal movement by Borelli in his *De motu animalium* (1681; Figure 9). Wann et al. [29] have overcome these simplifying assumptions by modelling the body as visco-elastic.

This approach together with Nelson's [30] assumption that skilled motor behavior is self-organizing by optimizing the motor economy via "minimal jerks", allows to model motor learning without instruction and supervision, that is, most kinds of natural movements. The difficulty with this approach is that if natural movements are acquired this way and if alternatively artificial movements as for instance in gymnastics need to be instructed and supervised, experimental analyses of this phenomena are difficult. Wann et al. have chosen as movements drawing ellipses but this very task imposes constraints upon the motor behavior that forces it to show minimal jerks and elasticity.

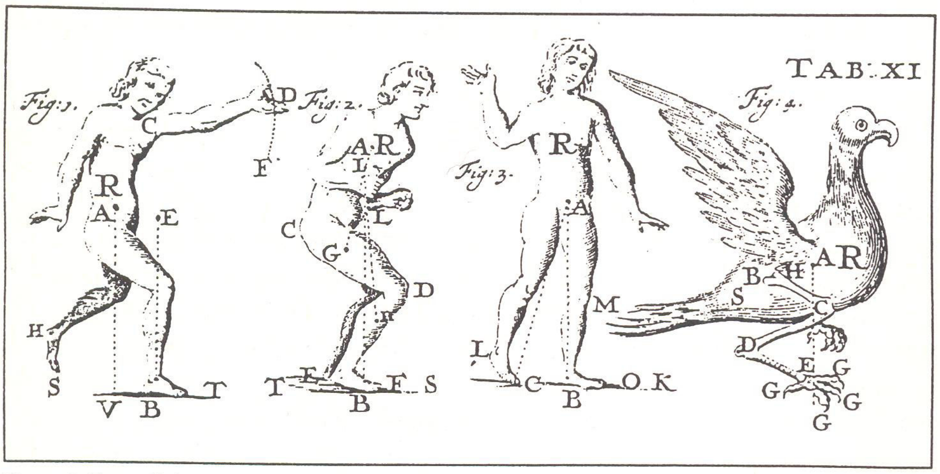

Figure 9 From G.A. Borelli's *de motu animalium* (1681) (reprinted by Springer, Berlin 1989)

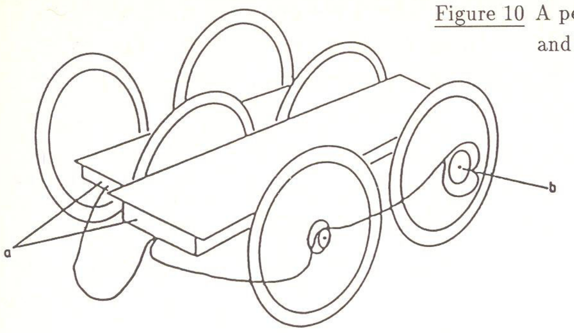

Figure 10 A pedalo with measuring devices for horizontal and vertical forces

In order to overcome these problems Zimmer & Körndle [31] have investigated riding a pedalo (see Figure 10) as a paradigm for motor behavior. The pedalo is a linear system but the man-pedalo system exhibits two kinds of non-linearity: (i) the learning process is not incremental because a perfect performance depends on a qualitative change in the control behavior, and (ii) even after the highest performance level has been attained, the behavior is stable only if the experimentally controlled velocity varies in a very small band. Below that it shows stochastic fluctuations and above that it consists of bursts of fast coordinated behavior followed by pauses.

Especially the non-linearity of the learning process has been analyzed by a series of experiments. The main results can be summarized as follows: (i) the overall smoothness of the transition of forces increases with learning (Figure 11 a, b, c; lower panels). (ii) In the beginning mostly vertical forces are applied to cause forward movement and the horizontal forces merely serve regulatory purposes (Figure 11a upper panels). After stability in controlling the system has been achieved, horizontal forces control the forward movement and the vertical forces are merely regulatory (Figure 11c; upper panels). (iii) The transition from the initial state to the final state is not linear as can be seen from the statistical analysis in Table 1.

The non-linearity of the learning process is revealed by the comparison of the net amount of directional changes in the initial, the intermediate, and the final learning state. That these changes occur more often on the intermediate level than on the low and high level indicates that the man-pedalo system switches from a stable state (control by vertical forces) to another stable state (control by horizontal forces) and that this transition leads to oscillations of the direction of forces. The initial stable state is characterized by extremely "jerky" downward control movements because in order to overcome the (stable) deadpoint singularity by means of the system's inertia, the vertical forces exerted by one leg have to increase up to this point then to cease and the other leg immediately has to take over. In the final state forward and backward forces alternate smoothly; this is possible because the deadpoints are extremely unstable.

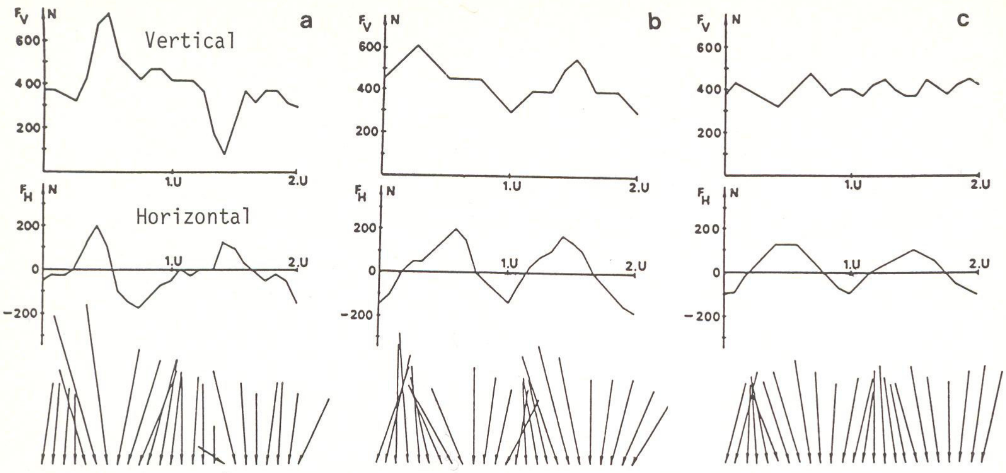

Figure 11 Forces (vertical F_V, horizontal F_H, and effective) in riding a pedalo; (a) at the beginning of the learning phase, (b) at an intermediate performance level, (c) at a high performance level

Table 1

physical data		performance level low (A)		intermediate (B)		high (C)
effective	mean	A	≈	B	B >>	C
forces	variability	A	>>	B	B ≈	C
directional	net amount	A	<	B	B >	C
changes	smoothness	A	<<	B	B <	C

$<$: $p < 0.05$, $<<$: $p < 0.01$

If the speed is externally influenced by a metronome, the second kind of non-linearity can be shown: A stable control of the speed is only possible at a medium rate of metronome clicks. Below that rate the drag and inertia of the system plus perturbations from the environment make the performance erratic and above that rate the control breaks down into bursts of high speed and pauses. This happens because very fast movements of the man-pedalo system necessitate the application of stronger vertical forces to overcome the unstable dead point singularities of the horizontal control. Consequently, once in a while the system gets entrapped in the stable singularity of the vertical control. Phase diagrams (Figure 12 a, b) reveal that this "window of stability" for the man-

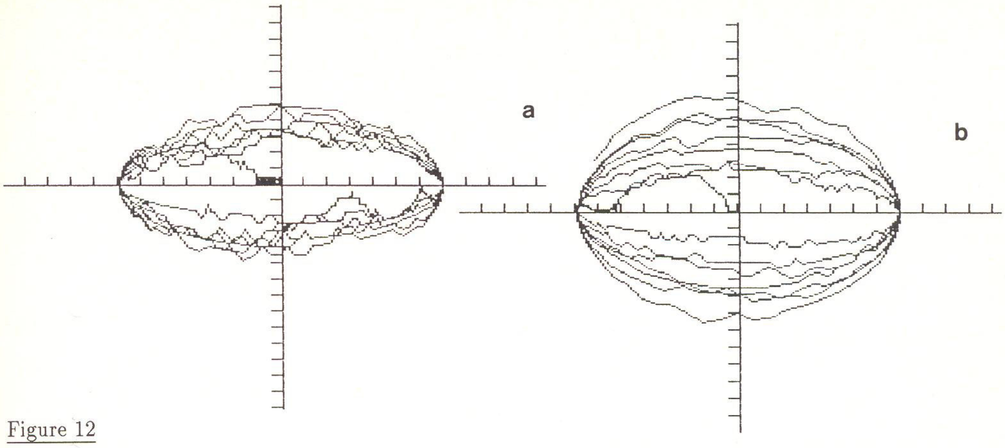

Figure 12

Phase diagrams for slowest possible movements in riding a pedalo; (a) with external perturbations, (b) without perturbations

pedalo system depends on the amount of external perturbation. If the surface is rough on which the pedalo runs, a controlled movement is possible at a very low metronome rate. At the first glance this is a paradoxical result because the addition of noise to a system usually does not result in a better functioning of the system and - viewed from the perspective of information processing - more degrees of freedom in the environment make a task more complex and therefore more difficult to execute. If, however, the controlled behavior of the system is regarded as the smooth and stable oscillation of forward and backward movements of the legs with singularities at the transition points, the 'noisy' environment breaks the attraction of these singularities and therefore allows the system to function smoothly even at very low velocities.

4. Conclusion: The Cost of Stability

As pointed out in the beginning, the search for stable conditions in perception and action is motivated by the following facts: (i) the channel capacity of sensory systems is limited (ii) perceptions and actions happen at specific times and places, and (iii) perceptions are always those of a specific observer with a specific perspective that reflects the environments as well as the observer's position and action in it. Therefore goal-oriented behavior is only possible in predictable, that is, stable environments. The described processes of order formation can be viewed as organism-environment coalitions: The effectivities of the organisms and the affordances of the environment mutually linked together result in a system that functions well - most of the time.

It is not perfect because the data it acts upon are necessarily incomplete or even fallible and because the processes of order formation are not effortless and

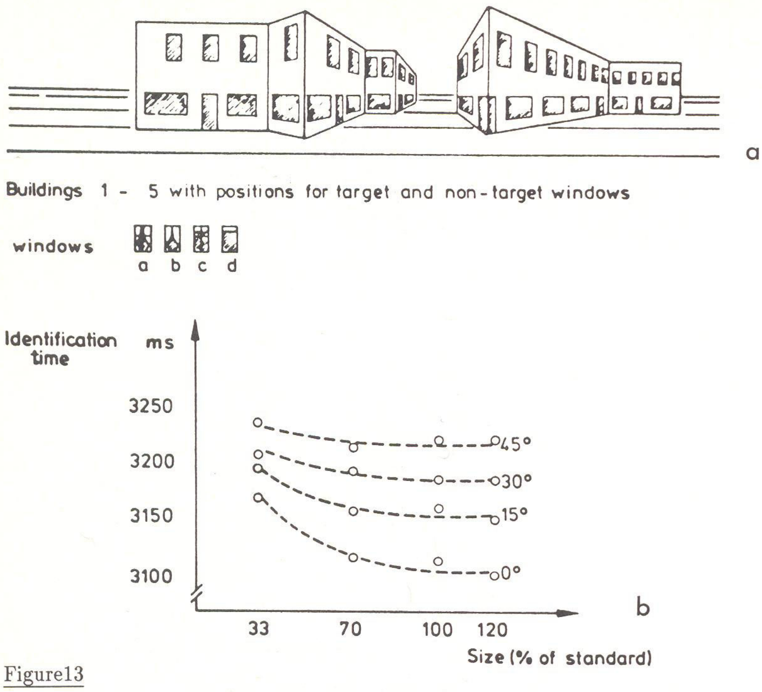

Figure13

The visual search task in [32]; (a) the targets and their possible locations in a perspective scene, (b) the relation of the identification times to size (%) and target orientation (°)

direct, they need attention and time and are therefore prone to malfunctions due to processing demands.

The effort necessary to recover spatial information from plane drawings is apparent in visual-search tasks [32], as depicted in Figure 13a. The subjects had to identify the location of a target (one special window frame) in a scene with apparent depth. On top of the general search time extra time is necessary to rotate the pictures and to rescale their sizes (Figure 13b). The rescaling and rotating can give rise to visual illusions if the general scene induces a perspective and accordingly an inappropriate constancy scaling [33] as in the case of the Ponzo-illusion. Odd perceptions of complex forms can also be induced by local tendencies toward stability, for instance in the Hering illusion, where the local stabilizing processes win over the general stability, that is, they bend straight lines and thereby reveal that form constancy and rigidity are only of relative importance for achieving stable percepts. If different criteria of stability lead to conflicting percepts the cognitive system seems to achieve solutions by a kind of simultaneous graceful degradation of these criteria. Experiments with "impossible figures" [34] have shown that from a certain degree of complexity upward pictures with back-ground fore-ground mixing or "impossible twists" are spontaneously reorganized by relaxing rigidity. A simplified example is shown

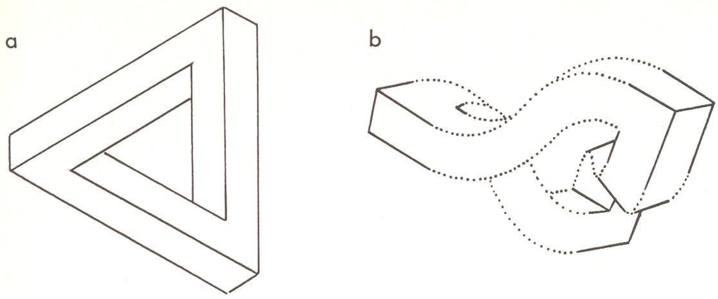

Figure 14

The possible Penrose triangle according to Hamaekers; (a) from a perspective where the beams appear straight, (b) rotated by 90°

in Figure 14, where the impossibly twisted triangle (a) is made possible by bending the beams. This result contradicts Hochberg's [35] model of foveal sampling and subsequent cognitive reassembly in picture perception and argues for the position that *at any time the best possible (that is most stable) percept* results even if it necessitates local compromises between criteria of stability.

Analogous processes are proposed for actions according to which motor behavior and its environment (spatial as well as temporal) tend towards stable interactions. These result in smooth changes of directions and magnitudes of effective forces. Singularities are overcome by regulating the forces in such a way that at these points the effective forces vanish. The 'cost' of such an order formation in motor behavior consists in (i) illusions of motion; for instance, the motion of a point at the circumference of a rolling circle is seen as a curtate cycloid and not as a normal cycloid, and (ii) problems of learnability; movements with accentuated sigularities (e.g. tango in dancing and the more difficult 'figures' in gymnastics) are not only hard to learn but tend also to 'degenerate' towards more stable forms of movement if not supervised and corrected permanently.

In conclusion, processes towards stability in perception and motor behavior allow fast and goal oriented orientation and action, however, their cost consist in a sometimes severe lack of adaptability for anomalous situations.

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