

# cognitive systems

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# ESSCS

## ON CONCEPTS OF "COGNITION" IN BIOLOGY

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### Abstract

Besides an introductory chapter on "cognitive" processes in the bio-molecular domain (part A), this essay presents some reflections on vertebrate behaviour from a neurocybernetic point of view. First, some comments are given on the problem of modeling organism-environment interactions (part B). It is shown how environmental features enter the nervous system by altering a behaviour-immanent sensorimotor circuit. In following a coarse phylogenetic line - with only consideration of three major stages (fish, tetrapodes, and primates) - it is argued that extensions of the sensorimotor circuits are paralleled by increasing complexity of locomotor behaviour, part C. The last part, D, deals with permanent bipedality of hominids and points to two consequences of the fact that arms and hands lost their locomotor function: (i) a compensatory drive towards object manipulations, and (ii) an additional quality ('Eigenquality') in experiencing own manipulations under visual selfcontrol.

The paper is intended to support a provoking hypothesis: Could the origin of aspects of selfconsciousness have been just (due to) an extra control loop of arm and hand movements ?

*"Even the highest evolved nervous system can never be wiser than its 'Afferenzen' (afferent informations) permit."*

(E. von Holst, 1950)

### Part A. On behaviour of biomolecules

If we believe in evolution, we accept that life originated in an aqueous environment. Whether we take a cell as the minimum condition which shows all categories of life phenomena, or even a precellular, molecular phase, makes no difference: if there was cognition it was without psychology.

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Biologists live largely within a man-made environment; the main problem of dealing with cognition at the infrahuman level will be to get rid of anthropomorphism. Did Konrad Lorenz do a big step forward (and backwards along evolutionary lines) by saying: '*Life itself is a cognitive process.*' ? (1973). Similarly, Humberto Maturana stated: '*Living systems are cognitive systems, and to live is to know.*' (private communication).

Even if we try to look for the physical forces involved in metabolism, no answer to the question of the appropriateness of the term "cognition" is given. Two sorts of forces help to bring about such "cognitive" processes:

1. Thermodynamic motion mixes the interactants in a chaotic manner until complementary structures "catch each other".
2. The "catching" is the sum of electrostatic forces exerted between *pattern-matching* surfaces. (Chapeville e.a. 1980)

Cognition at the molecular level can thus be seen as biophysical-chemical interactions, selective by pattern-matching between "spatially complementary" structures (note 1). An ever-changing medium providing a lot of variety of interaction partners in rapid succession, is the necessary precondition.

Now let us embark on the stream of evolution. After development of protective double layers, the *cell* shielded off hydrolytic influence from the aqueous environment. Catalytic interactions now worked within a spatially autonomous, but energetically and informationally *open system*. Food recognition and communication (sexuality !) were still mediated by molecular interaction with receptors "waiting" on the cell surface. Our chemical senses (taste and smell), hormone effects, and immunological "recognition", all work on the direct-contact-complementarity principle.

Contact problems had to be solved too, when cell colonies appeared and started a new, most successful level of life phenomena, that of multicellular organisms, the metazoans.

Size and volume of higher metazoans prevented external thermodynamic motion forces to push them around. Metazoans had either to stick to the ground (plants, and sessile animals), float more or less freely (e.g. some cnidarians), or invent *locomotion*.

## Part B. The basic sensorimotor system

"*Muscle moves the world*" (Ragnar Granit)

"*Behaviour is regular, but there are no regulators*" (J. Gibson)

B1. *Beyond a stimulus-response model*

Organismic movement must not be linear or random. *Orientation* must bring about the connection between organism and its needs (food, shelter, partners). This is where sense organs (note 2) are necessary, with connections to the nervous system, making it a central nervous system (CNS).

Let us describe that system in more detail. It consists of two sorts of elements:

Material elements:

- a brain, or central nervous system, CNS,
- *afferent* connections, leading from sense organs to the CNS,
- *efferent* connections leading from the CNS to muscles and glands,
- *association fibres*, connections within the brain.

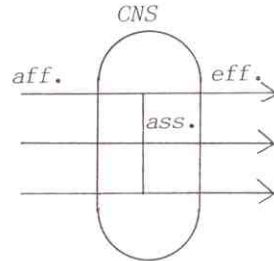


Fig. 1. Material elements

Dynamic elements:

- *efferent motor patterns*, which are excitation patterns for muscle innervations travelling from the CNS to the "effector" muscles, and
- *afferent sensory patterns*, excitation patterns from the receptors (on the surface or within the organism) to the CNS.

Apparently the *motor apparatus* is, at least partially, triggered from outside. The role of a CNS seems to be the coordination of stimuli from the *environment* (note 3) with movements. Behaviour was never independent of sensory input. Such a description shows how spontaneous movements can be explained as *reactions* Fig. 2.

Fig. 2. Stimuli and reactions, interactions with the environment  
(Figure after Ingènieros 1922)

$$X \xrightarrow{\text{stimuli}} O \xrightarrow{\text{reactions}} X'$$

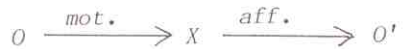
$X = \text{environment}, O = \text{organism}$

The *stimulus-response* model of classical *behaviorism* can be easily recognized, which gave rise to abundant literature, because an experimenter can administer artificial stimuli without bounds, and so manipulate resulting behaviour.

We shall now introduce a modified model, in order to avoid some serious disadvantages of that method. Part of the modification consists of adding some trivial assumptions. Let us consider a hypothetical palaeozoic fish as a starting point, in order to make the discussion more concrete. We avoid speculations on the origin of vertebrates.

The basic task of the CNS is the coordination of locomotion with sensory input. The critical, but trivial assumption is to recognize that an organism by locomotion changes its environment (Ashby 1952: p.37: "...muscles affect the receptors (by effects transmitted through the environment)...". "...most physiological experiments are deliberately arranged to avoid this feedback"). One could say that by locomotion the organism stimulates its own sense organs. Or, alternatively: sensory input is not independent of behaviour like locomotion.

Fig. 3. The organism (O) acting on the environment (X), and sensing it.



B2. Beyond a "straight-line" model

In vertebrates important sense organs are situated at the front of the organism. Locomotion is direction-selective, and constrained. This may have been the reason for the development of the CNS in the front position. The diagram of information channels may then be drawn in terms of loops.

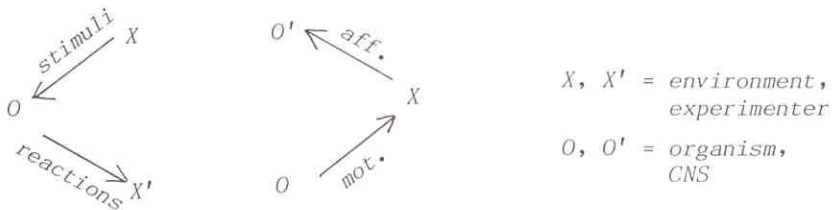


Fig. 4. Two kinds of interactions with the environment.

If we join the *behaviorist loop* (left) and the *self-stimulative loop* (right), we obtain a closed loop, which can serve as the basis of an *orientational system*:

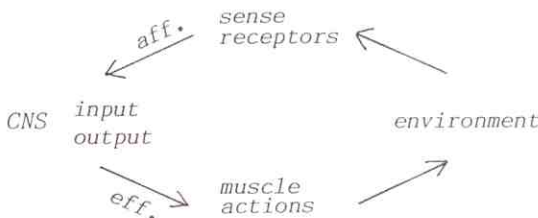
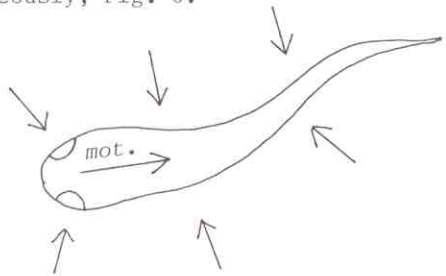


Fig. 5. An orientational system.

Several disadvantages make a drawing of a circuit a bad model for environment-related behaviour:

- a. The system is not a closed material circuit, it consists of various *dynamic* processes chained together. It runs as follows: motor neuronal discharge - transmission along motor pathways - contraction of muscles - displacement of the organism in the environment - perception of a *changing environment* - transmission along sensory pathways - feeding into the CNS, convergence (in yet unidentified ways) on the motor areas - activation of motor programs.
- b. *Environment change* is *subjective* experience, an external observer can only describe an organism in locomotion, he can only *imagine* an "environment-shift-effect" for the observed organism. Experiences attributed to another subject without verifiability for the observer, that is where *psychology* begins.
- c. Motor pathways leave the brain in nicely ordered, parallel fibres, sensory input is dispersed, coming from many directions. Often *several* sensory responses (vestibular (note 4), visual, tactile, chemical) are fed back simultaneously, Fig. 6.

Fig. 6. Multiple sensory responses.



- d. Regarding the multiple feedbacks from motor activity, the system can be viewed as an *amplifier*, regarding the vast input and the comparably "thin" output, it can be viewed as a *filter*:

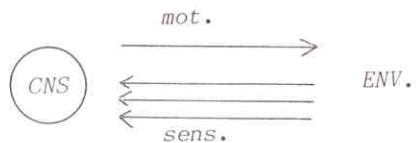


Fig. 7. Multiple feedbacks.

- e. The explanation of adaptation is a big problem. Apparently, the CNS can use its afferent information to react in an appropriate, oriented manner to environmental features. We call the behaviour of animals *adaptive*, often *goal-directed*. If so, the vast amount of sensory input must be filtered, selected, reduced, and finally be used as triggers and regulators for the motor apparatus. According

to J.Gray (1950), *motor control* in vertebrates seems to have proceeded from an endogeneous, preprogrammed, largely rhythmic type, as described for fish by E. von Holst (1969,1970), to an increasingly modifiable type of motor control dependent on complex sensory processing. From the brains of higher vertebrates there is anatomical evidence: the structures doing the information-processing of sensory input appear to have "overwhelmed" the motor apparatus.

The organism-environment interaction as a circular interaction has been introduced before by Victor von Weizsäcker and Jacob von Uexkuell. The first wrote a monograph "*Der Gestaltkreis*" (undertitled "*A theory about the unity of perception and movements*"). His figure reads as follows:

O= Organism

U= Umwelt = environment

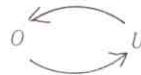
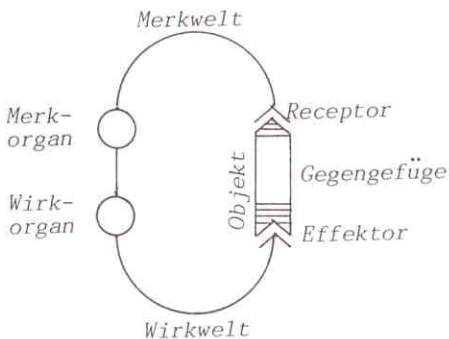


Fig. 8. Complementarity of organism and environment.

Being a neurologist, von Weizsäcker noticed *complementarity* in movement-perception acts and states a *mutual exclusion-principle* insofar as perception can be replaced by spontaneous movement (and vice-versa). He thus drew attention to the inseparability of movement and perception: "*sensomobility*". More elaborate is the *Funktionskreis* by von Uexkuell, a famous biologist. His figure:



Merkwelt= "world of perception"  
 Wirkwelt= "world of action"  
 Gegengefüge = environment as a structured whole

Fig. 9. *Funktionskreis* by von Uexkuell (1930)

His basic metaphor for the circuit is *Zange* (a pair of pliers), by the *Funktionskreis* the subject "grasps" the object.

### B3. Towards a dynamic model

We use a tree model to show the organization of our (human) NS but to arrive at it we have to turn the basic sensori-motor (or kin-esthetic) loop/circuit on its head. Showing the circuit "upside down" is defamiliarizing but at the same time it can help by the tree analogy – a fountain would do even better, by adding the temporal domain:

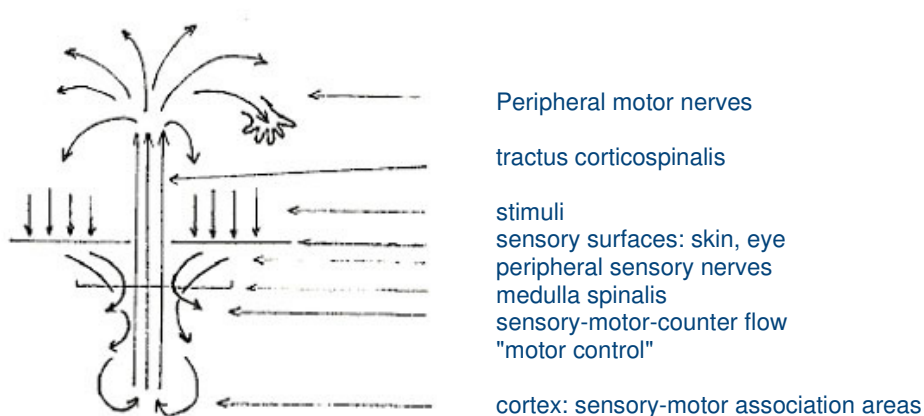


Fig.10.

The stem is the main motor output of the CNS/brain, the corticospinal tract leaving the head through the occipital foramen (in reality "down"wards) into the vertebrate column. In each intervertebral joint motor nerves sprout to the side innervating the arms and legs – thereby spreading out to the physical world, towards objects etc.

Touching means the objects push back, and this "echo" of the motor pulses "comes back" through the skin - now called sensory stimuli (see dropping arrows!) - and from the skin these converge towards the vertebral column. Running alongside the outgoing motor fibres, but backwards, the lemnisci (sensory bundles) enter as part of the spine's medulla the foramen, go to the thalamus and then spread into the CNS, its cortical areas.

"Cognition work" begins within the network between incoming sensory patterns feeding into association centers, then converging at the (pre-) motor centres to be released as the outgoing motor patterns.

The senses feed and canalize/constrain behaviour, but some of the sensory patterns "metamorphose" into motor ones – a sensorimotor short circuit, (for) rash action, happening in "mirror"- cells...

The spreading and convergence are aspects which in a diagram can only be shown if it were four-dimensional: the self-channeling function can be drawn schematically, Fig. 11. The fountain-metaphor is poor because some important senses are more linear than surface-like (e.g. the labyrinth), and nothing is explained on how motor patterns can be constrained by counter-flowing sensory ones. Actually, there is an area where interaction takes place: the reticulo-thalamo-cortical system. Multiple interactions by "circuits within the circuit" are



probable, see Fig. 11, see also Hernegger (1984), who gives a thorough discussion of development of the *formatio reticularis* during evolution.

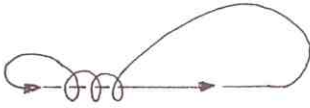


Fig. 11. A self-channeling system.

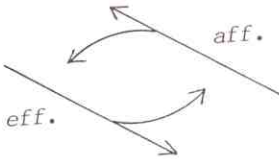


Fig. 12. Multiple interactions of "circuits within a circuit".

Another possibility is a mapping of the dynamical aspects only, the patterns flowing in various parts of the circuits.

#### B4. *Pattern matching by synchronicity*

Motor fibres and sensory fibres conduct patterns in contrary spatial directions (see above), but can be drawn in parallel as a function of time. This can be seen from an example how excitation patterns traveling in a functionally closed system can "match", which means one part of the circuit is "illustrating", "commenting" the other ("self-reference"). Just imagine a swimming fish. Because the labyrinth is stimulated only (but immediately) by acceleration, and the so-called *lateral line system* in fish monitors velocity of passing water, we can draw an episode (fish swimming, increasing and decreasing its velocity, finally hitting an obstacle) by just parallelling their patterns with the (loco)motor one.

The figure shows (apart from the terrible simplification) how different senses tell the same story differently. Take for example the lateral line system, it tells us that after hitting the obstacle there is still water flowing past the fish. Does that mean the obstacle is pushed ahead by the fish thereby slowing him down, or does it mean that obstacle and fish are situated in a river (the fish perhaps

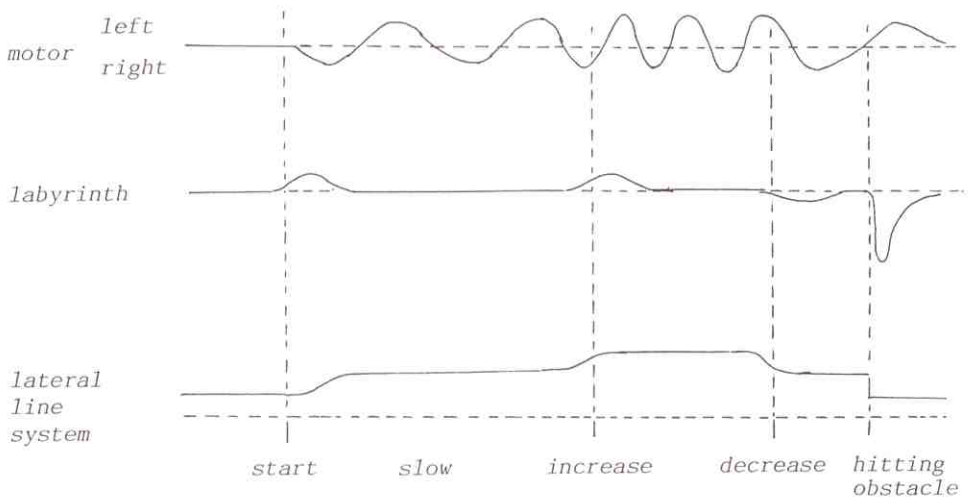


Fig. 13. Correspondence between traveling excitation patterns.

trying to smell at the obstacle, continuing to swim to prevent being driven off?) One could "ask" the visual and the olfactory sense, and so can the fish.

Two more things can be shown even in that sketch: Motor patterns are not altered much by sensory input (say environment), but patterns of the two senses are strongly dependent on motor acts and environmental features *together!* We might assume that dependence of the first sort will increase by locomotion *on* a formed and firm substrate (instead of *through* amorphous water), which is what J.Gray (1950) has described. How about the second dependence, the inseparability of self-stimulative and environmental effects in sensory patterns?

Will the visual sense, always regarded as the most accurate in "depicting" the environment, in "mirroring" it in a "photographic" way, show that dependence too? Let us sketch another episode, but reduce anthropomorphism.

First note that visual afference is dominating amongst our senses. Let us introduce some crude simplifications:

1. Consider only half-spherical eyes, placed in an exactly lateral position and built like an insect's eye, Fig. 14

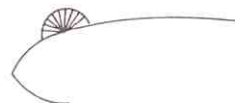


Fig. 14. Half-spherical eye. (from above)

2. Assume that there is no eye-muscle activity.

3. Only two rows of retinal elements are recorded, a horizontal one and a vertical one, Figure 15.

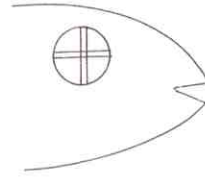


Fig. 15. Vertical and horizontal visual detection (from the side).

4. Consider the following situation: Our fish swims slowly and passes both a nearby and a far-off stationary small object. Simultaneously a swarm of fish swims against its own direction and one of the fishes passes exactly the horizontal line of "retinal" elements. Finally our fish also bumps into an obstacle.

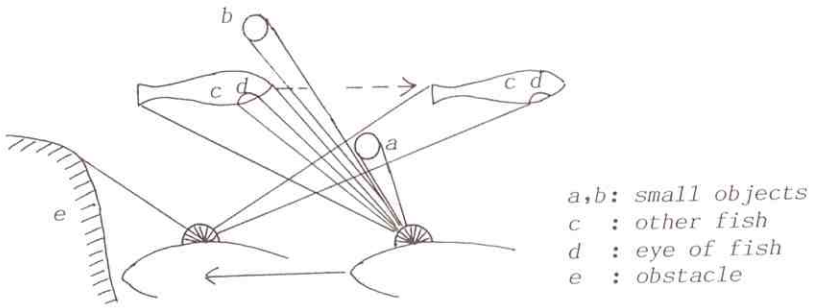


Fig. 16. View from above.

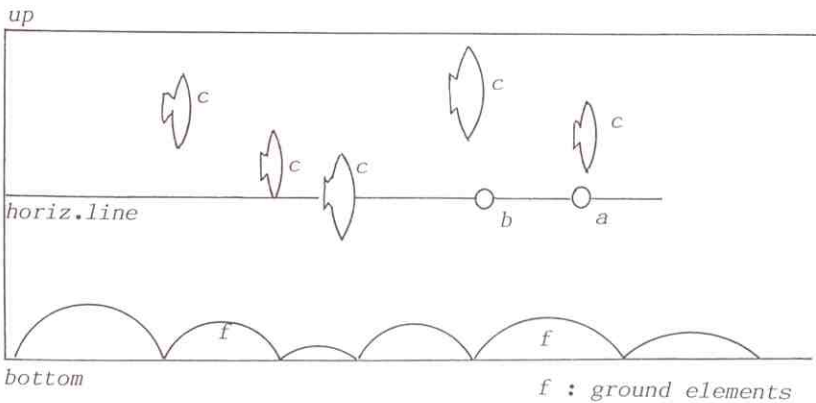


Fig. 17. "Slot eye", vertical row.

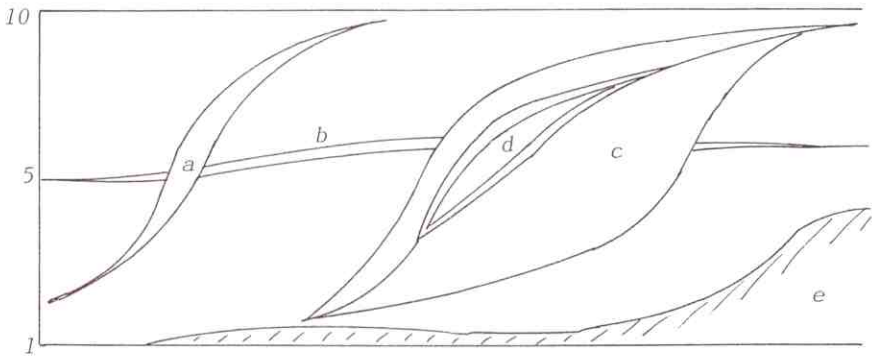


Fig. 18. "Slot eye", horizontal row.

Apparently we can identify much easier with the vertical row, probably because locomotion is perpendicular to it. Anyhow, the sketches show what the visual system must integrate to represent the environment as a (pseudostatic) picture. Two more remarks: Surely eye movements will be used to "follow" a passing object by stretching it to "real" dimension. If the fish detects a "homogenous pattern which increases in a symmetrical way in the frontal part of *both* eyes", this means impending collision.

In general, as J.Gibson (1979) has shown, the full two-dimensional retinal image-pattern changes with locomotion in a regular way: parts of it leave on one side, other parts enter at the opposite border, as the "frame" of the retinal image scans along the environment. So the motor pattern of locomotion is *not* primarily represented *within* the image, but the shift-pattern of the whole image is "in tune" with it. The pattern of appearance and disappearance of visual pattern elements does represent direction and time-dependent properties of locomotion (eye movements excluded).

We are thus led to the conclusion that information about the environment enters the organism by interfering with an already patterned sensorimotor "carrier system". Stimuli in this way do not trigger reactive behaviour, but they are modulating, superimposing on a continuously interacting organism-environment-system (note 5). External observers will have access to these processes only when recording techniques during free locomotive behaviour are developed.

So far the sensorimotor system was introduced with regard to animals moving "freely" like a fish. Every muscle action (except digestion and

respiration of course) will influence the relationship of the whole organism to its environment. But evolution did not stop with fish.

### Part C. Tetrapodes or how to move a marionette

What the selective pressures were that led vertebrates to develop a *neck* and *legs* that carry a body, is still subject of discussion, surely orientation and locomotion became accordingly more complex. In the course of evolution from fish via amphibia and reptiles to mammals, the *head* became mechanically separated from the rest of the body and four separated lever systems came to carry an (almost) passive trunk. New dimensions of behaviour were added by the interposition of atlanto-occipital, cervical, shoulder, elbow and ankle joints. The sensorimotor system had to integrate these new internal sources of disturbance. Let us try to point out a few of the problems to be solved by an ordered interplay between the anatomical-mechanical and sensorimotor-behavioural systems. We take mammals as representative.

#### C1. *Posture control*

Most of the reptiles pull and push their belly across the substratum. Mammals have to balance their body, fighting gravity even when standing. During locomotion certain patterns of gait (walk, trot, canter, gallop) produce the result of a smooth environmental pass-by (Gibson 1979).

#### C2. *Non-locomotion*

Distinctions must be made between motor acts resulting in body or head movements feeding back environment shift, and non-locomotive ones like scratching or tail-wagging. Because such non-locomotive movements are not monitored by vision or touch, another feedback is necessary.

#### C3. *Proprioception*

Proprioception offered the possibility for an internal information loop. Sense organs within muscles and joints, or next to them give the CNS "insight" into muscle contractions and joint positions. Posture and locomotion are now controlled along two pathways: the orientational circuit and the internal proprioceptive one (note 6).

#### C4. *The reafference principle*

Turning the head produces a striking subjective change of the visual environment (much the same as eye movements) without affecting the locomotor apparatus. Still orientation is not disturbed! Erich von Holst

and Horst Mittelstaedt (1950) introduced a solution for these achievements not to be explained by reflex terminology. If there is no reaction to an environment shift effect following a motor command, it must be counteracted, extinguished - why not by a "copy" of the very motor command? Except for a few studies on the "overload-protective" function of such attenuation of self-induced afferences (Stein, 1978), the importance of the reafference principle might not yet be adequately understood.

#### C5. Manipulation

Interestingly, manipulation started with the snout! The principle is as follows: A paired system of levers is arranged for a coordinated snapping movement with continuous variability in distance and compression. Capable of "instant adaptation" this pair of pliers has evolved in fish and has changed anatomical parts since, but gripping, holding, carrying are functions fully developed mostly in mammals and birds.

Held objects are integrated in the mechanical body system, they are "limbs" but without muscular or nervous connectivity. This means that the existing sensorimotor programs must adapt to additional loads - new coordinations between labyrinth, neck muscles and locomotor apparatus have to be, and are established (Horn 1983).

Evolution did not stop with tetrapodes. On the contrary, two ways of increasing neurocybernetic complexity were successfully followed. Birds by flight, and primates by tree climbing, really conquered another, the third spatial dimension. Leaving birds aside we look for the major consequences of "quadrumanuality" to arrive finally at the latest condition: bipedal bimanuality.

#### Part D. Bipedality

Gravity may be the most important single factor in the physical domain determining anatomical features. For supporting body weight 3 legs would do, but transport without jumps requires 4 or more. In case we accept a brachiatory phase in the course of hominization, "support" of body weight can be achieved by hanging on *one* arm, locomotion by alternation of arms and/or legs (4 of them plus a tail in some species can be used). Again we can only hint at some problems for the sensorimotor system.

#### D1. Tension reversal

We can easily see how mechanical connections remain the same (contact between limbs and environment) but functional chains ("causality") change directions. Muscles (in hanging *flexors* "carry" body weight, in standing *extensors* support it) and the sensorimotor system must rearrange forces and impulses, the labyrinth is forced to accomo-

date new, rotatory accelerations.

#### D2. *Spatial abilities and selfmonitoring*

Many authors have referred to the importance of eye-hand coordination in tree *climbing* and the development of binocular vision for depth perception, here we need only stress the tight interaction of the two achievements and their underlying gain in neurocybernetic complexity: For the first time in evolution animals see what they are doing. (Canids, carnivores and rodents either lack specialised hands or cannot afford reducing attention to further environment). Directly controlled reaching establishes a small, but radically new range of activity around the animal: Intention movements themselves can be observed, for the first time the aim and its approach-activities are monitored, even their contact is observable. Surely direct calibration of *distance* is qualitative progress in environment-adapted behavior.

#### D3. *Bipedality*

Presently the big apes are by far the most skilled in "instrumental technology" (ladder building, lever use, sponge use, washing, throwing, beating, noise production), but of their predecessors probably only few left the woods and adopted bipedality for locomotion. The reasons are not yet fully understood, but an interaction of several factors is probable (Lovejoy 1981). Anyhow, these forelimbs,

- a hundred of million years serving as stabilising and propelling fins with "environmental" control, then
- even longer serving as propping legs with additional proprioceptive control, further
- maybe a dozen million of years serving as suspending arms with additional visual control were for the first time *freed from stabilising and locomotive functions.*

What to do with a pair of legs without regular, firm contact with the substratum? (Besides: Not for the first time in evolution did the liberation of forelegs have positive consequences for *cognitive* abilities of the species involved: Arthropods developed antennae for touching and exploring tasks similar to the use of forelimbs by hominids. The truly manipulative function, however, is in arthropods performed by *another* pair of lifted legs called mandibles...)

#### D4. *Hands: pacemakers for hominid cognition?*

It is assumed here that arms and hands gained new functions, that their sensorimotor apparatus, "running free", chose new interaction partners. Because head and vision left proximity to the ground, parts of the environment had to be lifted to the manipulative distance.

Voluntary motor acts had to concentrate on the handled object and move it with little effort (compared to levering the whole body).

These motor acts which are "individual-bound", "environment-absolute", established a sensorimotor circuit separated from the locomotion-driven one. One can say that for forelimbs the environment has shrunk to a passively moving object, that "behaviour within" had become "behaviour on".

Let us stop here. Bipedality anteceded hominid brain enlargement as is shown by fossil evidence. Maybe consequences emerging out of the progressive sensorimotor complication contributed to that development.

### Notes

(1) The most common metaphor for spatially complementary structures in everyday life is the "key-lock" system. One must not forget that this system works by external forces only: Human cognition does the selection between patterns, and human hands provide energy for the mechanical interaction. Yet the *spatial logic* involved, the "convexity-concavity-interplay" is comparable on both macroscopic and molecular level. (At the time when the self-assembling activity of biomolecules was not recognised, metaphysical "explanations" in vitalistic terms were given ...)

(2) *Euglena* may serve as a minimum model for an orientation-locomotion-system. This is a famous unicellular organism propelling itself by flagella and choosing bright-lightened environments with the aid of a microscopic eye-spot.

(3) The term *Umwelt* was coined by von Uexkuell to cover only such aspects of the environment which are relevant to a single species. I use *environment* in that sense, automatically indicating that our human concepts of environment can differ from the one represented in various animal species.

(4) The most important feedback of locomotor activity might be the *labyrinth* registering change of momentum in any direction. Methodological problems - the hidden location in the head (any electrodes would interfere with free locomotion) and the a priori-like information-processing - make that sensory mode a remote, "underlying", inconspicuous one. These characteristics may indicate a fundamental role within the "sensory chorus".

(5) Humberto Maturana in his terminology might say stimuli *do* trigger structural changes in the system, but nevertheless conservation of organization is not endangered by such "perturbations".

(6) Proprioceptive feedback can in a certain way replace the orienta-



tional circuit, e.g. complex nocturnal activity becomes possible. Reptiles can not use this behavioural niche, but homiothermal mammals can (and possibly outdated the dinosaurs in that way).

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This page can help understanding the following illustration (edited and added 2015)

### B3. Towards a dynamic model

We use a tree model to show the organization of our (human) NS but to arrive at it we have to turn the basic sensori-motor (or kin-esthetic) loop/circuit on its head.

Showing the circuit “upside down” is defamiliarizing but at the same time it can help by the tree analogy – a fountain would do even better, by adding the temporal domain:

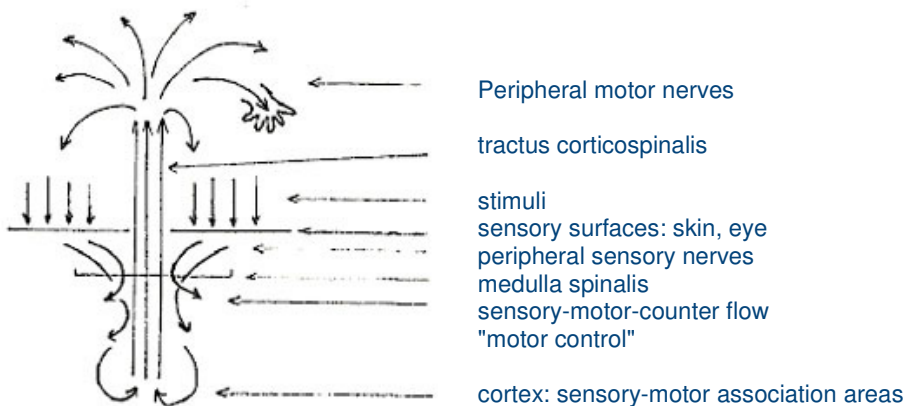


Fig. 11

The stem is the main motor output of the CNS/brain, the corticospinal tract leaving the head through the occipital foramen (in reality “down”wards) into the vertebrate column. In each intervertebral joint motor nerves sprout to the side innervating the arms and legs – thereby spreading out to the physical world, towards objects etc.

Touching means the objects push back, and this “echo” of the motor pulses “comes back” through the skin - now called sensory stimuli (see dropping arrows!) - and from the skin these converge towards the vertebral column.

Running alongside the outgoing motor fibres, but backwards, the lemnisci (sensory bundles) enter as part of the spine’s medulla the foramen, go to the thalamus and then spread into the CNS, its cortical areas.

“Cognition work” begins within the network between incoming sensory patterns feeding into association centers, then converging at the (pre-) motor centres to be released as the outgoing motor patterns.

The senses feed and canalize/constrain behaviour, but some of the sensory patterns “metamorphose” into motor ones – a sensorimotor short circuit, (for rash action, happening in “mirror”- cells...