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NAVIGATION, CONSCIOUSNESS AND THE BODY/MIND »PROBLEM«*)

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Exploitation of an unconscious veto mechanism, mediated by a specific cortical circuit, and made possible by an adequate very-short-term memory span, paradoxically requires conscious awareness. Part of the same circuit, interacting with other brain components, permits internal simulations of the body's interactions with the environment, thereby providing the basis of mind.

KEYWORDS: Consciousness, veto mechanism, muscular movements, body/mind problem.

It was recently suggested that the evolutionary advantage of consciousness lies in the power of choice it gives an animal (Cotterill, 1995). But neural networks of the feedforward type also choose (North, 1987), as when they *un*consciously discriminate between the letters T and C (Rumelhart *et al.*, 1986). How does choice in conscious animals differ from this neural-network variety?

A feedforward network's choice incorporates non-biological features; it is helped by *grandmotherization* of its input and output neurons, these being *given* discriminative abilities (Crick, 1989). And such networks do not have to choose between temporally-extended events, which are characteristic of animal behaviour; grandmotherizing a *sequence* of neural signals is not an easy task. Finally, feedforward networks are merely fed with information, and their outputs are read off by intelligent agencies; they usually do not acquire experience of their own »volition«. Animals *do* (Clark, 1997); the environment is just as much a black box as is the brain of the creature exploring it (Cotterill, 1995).

Conscious animal choice is well illustrated by *navigation*. One dictionary definition of this word is `methods of determining a ship's position and course by the principles of geometry and nautical astronomy'. These are used by a navigator. The other meaning, more suitable for the person in charge, is commonly applied to explorers of bygone days; it refers to

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navigation in the general sense. Conscious animals are such navigators, probing their environments through (sequential) muscular movements, including (in advanced creatures) those of the vocal apparatus.

It was postulated (Cotterill, 1995) that acquisition of information is always an active process, even when merely the upshot of thought. Such accumulation is not *necessarily* conscious, however. For example, each walking stride is effectively a question: *is the ground still there*? Only when we encounter an irregularity, a hole perhaps, do our motor explorations suddenly become conscious.

Active information procurement inevitably takes time. Signals must pass to muscles, and reafferent signals must return via relevant sensory modalities. Proprioceptive information must simultaneously return from muscles, related joints and body surfaces. Libet *et al.* (1979) showed that about 500 ms elapses before we become conscious of an event, so Carpenter (1996) is right in suggesting that consciousness makes us observing bystanders, because we are informed too late of our actions.

Libet (1989) discovered a veto mechanism requiring considerably less than 500 ms, and deduced that this salvages free will (or at least free wont!). That conclusion is undermined by the observation that countermanding processes are just as automatic as the original movements (Carpenter and Williams, 1995). If neither a motor act's initiation nor its last-moment veto are freely willed, however, what advantage would they confer? How could unfree choice be more useful than the mechanical discrimination performed by feedforward neural networks, or by creatures devoid of consciousness? The benefit is profound: *real-time choice (or veto-on-the-fly, as it could be called), even in the absence of free will, would still be an enormous advantage to the animal.*

An insect also explores and makes choices. But when about to make a move, it never suddenly »realizes« the significance of its intended action and then vetoes it, even though the vetoing might perforce be mechanical and deterministic. This ability could sometimes make the difference between life and death. We, and our sufficiently close evolutionary relatives, do possess such a mechanism, as the above-cited studies demonstrate. The Carpenter and Williams work merely goes farther, by showing that free will need not be invoked.

Why should exploitation of this deterministic mechanism produce consciousness? Why could this unfree process not be carried out unconsciously? The answer lies in that word navigation. As those ancient mariners navigated the globe, their routes were dictated by environmental feedback; encountering an obstacle – impenetrable isthmus, unfriendly natives – they changed course, as recorded on their charts. Our body/mind systems can likewise switch tactics and the process, although deterministic, also relies on feedback, from the environment or from our recollections of it, or from both simultaneously.

But what is our system's counterpart of those indispensable charts;

where is *our* record of the muscular route recently taken? It is present, though only fleetingly, in the muscles themselves. Their states, and the rates of change of those states, are perpetually monitored by the tendon-organ/muscle-spindle apparatus, and although the mechanism is surreptitious, the overall system *is* aware of these parameters (Goodwin *et al.*, 1972; Lethin, 1977). The record persists over the span of very short memory (Edelman's *remembered present*, 1989; Humphrey's *thick moment of time*, 1992). Our systems are thus continually apprised not only of our surroundings, but also of their significance for us; they satisfy Sommerhoff's (1996) canonical requirements for conscious awareness!

What is the underlying neuronal circuitry? It was suggested (Cotterill, 1997) that consciousness requires planning of movement to be *actively proceeding*, and that the phenomenon arises through signals passing around a closed circuit consisting of the sensory cortex (SC), the premotor area (PM), and the thalamic intralaminar nuclei (TIL). In the absence of coupling to external stimuli, activity in this circuit was conjectured to underlie thought. The model invoked schemata, a schema being a reproducible co-activation of neurons linking a specific pattern of motor-planning activity (in the PM) to appropriate SC activity (reproducible because schemata are held in memory). Recruitment of an appropriate schema, or set of schemata, during overt motor exploration of the environment, or its simulated surrogate (i.e. *thought*), is presumably a self-organizing process (Haken, 1996); whence the temporal latencies measured by *Libet et al.* (1979) and by Carpenter and Williams (1995).

Purpura and Schiff (1997) suggested that awareness additionally requires a second closed circuit, also comprising the SC and PM, but including the anterior cingulate (AC). This does not jibe with the fact that bilateral removal of the AC, for the relief of chronic pain, does not preclude consciousness. But the AC could be intimately involved in the above veto-on-the-fly mechanism. It is noteworthy that there is a connection between the AC and the nucleus reticularis thalami (nRt) (Cornwall *et al.*, 1990; Lozsádi, 1994). The nRt regulates activity in the thalamus, including the TIL, thereby directing the focus of attention (Crick, 1984). Finally, the AC is involved in pain perception (Talbot *et al.*, 1991). Collectively, these facts suggest that this second circuit could indeed mediate the above veto function, through the AC forcing the nRt to divert attention toward possible danger, somehow depressing the motivational level below the threshold for movement (see figure 1).

With consciousness emerging as an indispensable servant of the unconscious (in higher species), one could call this *quasi-behaviourism*. The fascinating thing is that by requiring members of sufficiently advanced species to be a captive audience of their own motor acts, the evolutionary innovation of veto-on-the-fly gave its possessors a decisive advantage, and at the same time permitted their systems to acquire knowledge

about the environment through one-shot learning. This contrasts with the more gradual conditioning seen in creatures devoid of consciousness.

Finally, turning to a particularly venerable issue, the internally-simulated navigations (Damasio's *as if* processes, 1994) mediated by the SC-PM-TIL-SC loop can draw upon the predictions provided by the cerebellum (Miall *et al.*'s *what if* processes, 1993) and the planning capabilities provided by the prefrontal cortex (Ingvar's *memory of the future*, 1985), while automatically notifying the body of their significance. Seen in this light, there is no *problem* of body/mind, merely a *situation* of body/ability-to-simulate-body's-interactions-with-environment.

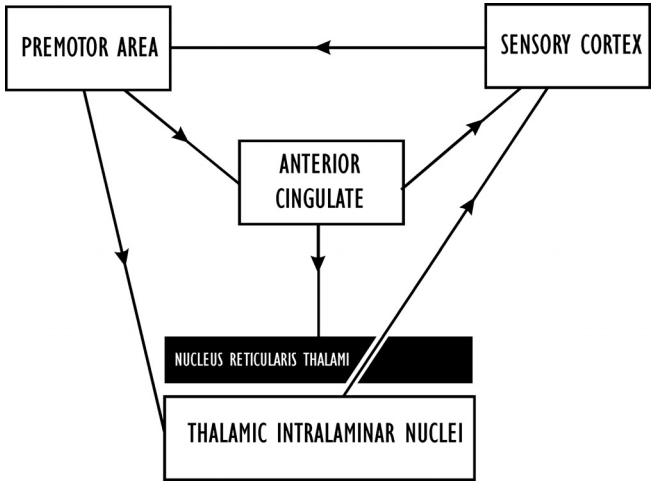

Figure 1. The core circuit that mediates the veto-on-the-fly mechanism comprises the brain regions shown here, the sub-circuit consisting of the sensory cortex (SC), the premotor area (PM) and the thalamic intralaminar nuclei (TIL) serving consciousness itself. This is supported by the observation, by Kinomura *et al.* (1996), that the PM, TIL and SC are all active during attention. It should be noted that the link between the latter two components passes through the nucleus reticularis thalami (nRt), which acts as a gate (its inhibitory effect here being indicated by the black colour). This gate, in turn, is under the control of the anterior cingulate (AC), and also of the brainstem reticular formation (not shown), the latter dictating the sleep-wake cycle. The AC is known to be involved in the perception of pain, so it is well suited to the job of applying the veto. It is important to note, however, that consciousness is not dependent upon the presence of the AC; indeed, bilateral cingulotomy patients are as conscious as normally-endowed people.

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REFERENCES

CARPENTER, R.H.S. & WILLIAMS, M.L.L. (1995) Neural computation of log likelihood in the control of saccadic eye movements. *Nature*, **377**, 59-62.

CARPENTER, R.H.S. (1996) *Neurophysiology*. London: Edward Arnold.

CLARK, A. (1997) *Being There – Putting Brain, Body and World Together Again*. Cambridge, MA: MIT Press.

CORNWALL, J., COOPER, J.D. & PHILLIPSON, O.T. (1990) Projections to the rostral reticular thalamic nucleus in the rat. *Experimental Brain Research*, **80**, 157-171.

COTTERILL, R.M.J. (1995) On the unity of conscious experience. *Journal of Consciousness Studies*, **2**, 290-312.

COTTERILL, R.M.J. (1997) On the mechanism of consciousness. *Journal of Consciousness Studies*, **4**, 231-247.

CRICK, F. (1984) The function of the thalamic reticular complex: the searchlight hypothesis. *Proceedings of the National Academy of Sciences, USA*, **81**, 4586-4590.

CRICK, F. (1989) The recent excitement about neural networks. *Nature*, **337**, 129-132.

DAMASIO, A.R. (1994) *Descartes' Error – Emotion, Reason and the Human Brain*. New York: Grosset-Putnam.

EDELMAN, G.M. (1989) *The Remembered Present – A Biological Theory of Consciousness*. New York: Basic Books.

GOODWIN, G.M., MCCLOSKEY, D.I. & MATTHEWS, P.B.C. (1972) Proprioceptive illusions induced by muscle vibration: contribution by muscle spindles to perception? *Science*, **175**, 1382-1384.

HAKEN, H. (1996) *Principles of Brain Functioning – A Synergetic Approach to Brain Activity, Behavior and Cognition*. Berlin: Springer.

HUMPHREY, N. (1992) *A History of the Mind*. London: Chatto & Windus.

INGVAR, D.H. (1985) »Memory of the future«: an essay on the temporal organization of conscious awareness. *Human Neurobiology*, **4**, 127-136.

KINOMURA, S., LARSSON, J., GULYÁS, B. & ROLAND, P.E. (1996) Activation by attention of the human reticular formation and thalamic intralaminar nuclei. *Science*, **271**, 512-515.

LETHIN, A. (1977) Muscle tone and feeling. *Energy and Character*, **8**, 42-48.

LIBET, B., WRIGHT JR, E.W., FEINSTEIN, B. & PEARL, D.K. (1979) Subjective referral of the timing for a conscious sensory experience: a functional role for the somatosensory specific projection system in man. *Brain*, **102**, 191-222.

LIBET, B. (1989) Conscious subjective experience vs. unconscious mental functions: a theory of the cerebral processes involved. In R.M.J. Cotterill (ed.) *Models of Brain Function*. Cambridge: Cambridge University Press.

LOZSÁDI, D.A. (1994) Organization of cortical afferents to the rostral, limbic sector of the rat thalamic reticular nucleus. *Journal of Comparative Neurology*, **341**, 520-533.

MIALL, R.C., WEIR, D.J., WOLPERT, D.M. & STEIN, J.F. (1993) Is the cerebellum a Smith predictor? *Journal of Motor Behavior*, **25**, 203-216.

NORTH, G. (1987) A celebration of connectionism. *Nature*, **328**, 107.

PURPURA, K.P. & SCHIFF, N.D. (1997) The thalamic intralaminar nuclei: a role in visual awareness. *The Neuroscientist*, **3**, 8-15.

RUMELHART, D.E., HINTON, G.E. & WILLIAMS, R.J. (1986) Learning internal representations by error propagation. In D.E. Rumelhart & J.L. McClelland (eds.) *Parallel Distributed Processing*. Cambridge, MA: MIT Press.

SOMMERHOFF, G. (1996) Consciousness as an internal integrating system. *Journal of Consciousness Studies*, **3**, 139-157.

TALBOT, J.D., MARRETT, S., EVANS, A.C., MEYER, E., BUSHNELL, M.C. & DUNCAN, G.H. (1991) Multiple representations of pain in human cerebral cortex. *Science*, **251**, 1355-1358.