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Autarchy and Openess in Living Systems

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Hebb postulated that a central requirement for living beings is the relative independence from stimuli. The Landauer–Bennett information–theory theorem can provide a theoretical basis for this fundamental feature of life. It is shown that living organism alternate periods of autarchy and periods of entropic and energetic openess. Two main processes are used in order to reduce the differences between the result of the organism's autonomous computation and the external stimuli: Either a mechanical assimilation of the self by the environment or the accommodation of the environment to the self.

KEYWORDS: Self; autarchy; openess; assimilation; accommodation; mutual information; anti–feedback; representation.

The most important problem in understanding living beings and the one that still represents a true mystery is the relative independence of "internal choices" from external stimuli (see [Hebb, 1949]; see also [von Hayek, 1952, 10–11.]), the so–called *equivalence of stimuli*, already introduced in psychology by Lashley [Lashley, 1942]. Similarly, Bernstein acknowledged that the relationship between movement and the innervational impulse that evoke it was not univocal, in the sense that

a given impulse can produce completely different effects under different conditions (see [Jeannerod, 1988, 27–28] and [Jeannerod, 1999]). An information–theory theorem can represent the key for understanding this basic structure of living beings.

It is the Landauer–Bennett theorem, according to which it is possible to process information without energy expenditure provided that there is no information selection [Bennett, 1973, Bennett, 1982] [Landauer, 1961, Landauer, 1996]. This assures the possibility of information processing in complete autarchy, that is, without dependence on previous physical conditions. As a matter of fact, already [Hebb, 1949, 60] understood that a necessary requirement for the independence from external stimuli is the possibility for the organism to act, in some temporal windows, as a closed system, even if at that time the mechanism could not completely be understood. For this reason, he [Hebb, 1949, 121] introduced the concept of *intrinsic* organization of cortical activity as opposed to the organization imposed on the cortex directly by sensory events. This line of research was also further pursued by Maturana and Varela [Maturana and Varela, 1980], who spoke of the neural circuit as a closed system.

In order to understand this feature, let us start with an ordinary complex system. In such a system, there is a continuous energetic and entropic flux from the environment to the system and vice versa. Obviously, the conditions that give rise to a complex system are in general very specific. For instance, Bénard cells can come out if two plates above and below some fluid are warmed up to a certain critical temperature. However, these conditions are not controlled by the system and in general give rise to a deterministic output, even if some aspects of the process (like the sense of rotation of each cell, though the ensemble of the cells rotate according to precise rules) are not specified. Completely different is the case of any living organism. Here, a membrane or some other mechanism assures a sharp division between self and non–self, so that certain exchanges with the external environment are controlled [Llinás, 2001]. Such a structure allows for the possibility that certain physical mechanisms of the organism are protected against external influences, and can therefore become the physical support of an autarchic computation. In the simplest case, a computation mechanism can be seen as a complex system that, led out of some equilibrium situation, will spontaneously evolve up to another equilibrium situation or minimum. This model have been largely employed for the domain called *computational brain* [Churchland and Sejnowski, 1992, Churchland, 1995]. The critical point is that a complex system has in general several minima, and, even if there is a best minimum, locally perhaps there are other minima

that are more easily accessible [Kauffman, 1993]. There are very easy examples of systems with several stable states (multistability). For instance (see [Haken, 1977, 105–113]; also [Haken, 1991]), let us consider a one–dimensional system ruled by the classical equation

$$m\ddot{q} + \gamma\dot{q} = F(q) \ , \qquad (1.1)$$

where m and q are the mass and the position of the system, respectively, $\dot{q}$ its first time derivative (its speed), $\ddot{q}$ its second time derivative (its acceleration), F represents some driving force acting on the system while γ some damping force. Assuming that m is very small and damping very large, we may neglect the first term on the lhs, and by choosing an appropriate time scale

$$t = \gamma t' \ , \qquad (1.2)$$

we may also eliminate the damping constant γ, so that Eq. (1.1) can be written in the simplified form

$$\dot{q} = F(q) \ , \qquad (1.3)$$

Equations of this type are very common in ecology or biology, where they describe the multiplication of cells or bacteria. We can consider in particular a system subject to a potential V, such that

$$F(q) = -\frac{dV}{dq} \ . \qquad (1.4)$$

If we consider the case of an anharmonic oscillator, the force F is given by

$$F(q) = -kq - k_1 q^3 \ . \qquad (1.5)$$

k and k_1 are here two parameters. Then, the equation of motion reads

$$\dot{q} = kq - k_1 q^3 \ . \qquad (1.6)$$

For $k < 0$ see Fig. 1.1 (there are here two points of minimum).

Let us suppose that the process of falling in a minimum is initially completely random. Obviously, the protected system will fall in an arbitrary point of minimum, provided that it is easily accessible. This "choice" by the organism will be translated in some effective operation (will "switch on" some mechanism, often represented by one or more proteins) where some work is done [Kauffman and Clayton, 2006]. Here, the energetic and entropic flux is again allowed. It is interesting to recall that Ashby [Ashby, 1956] understood cybernetic systems as informationally closed and energetically open.
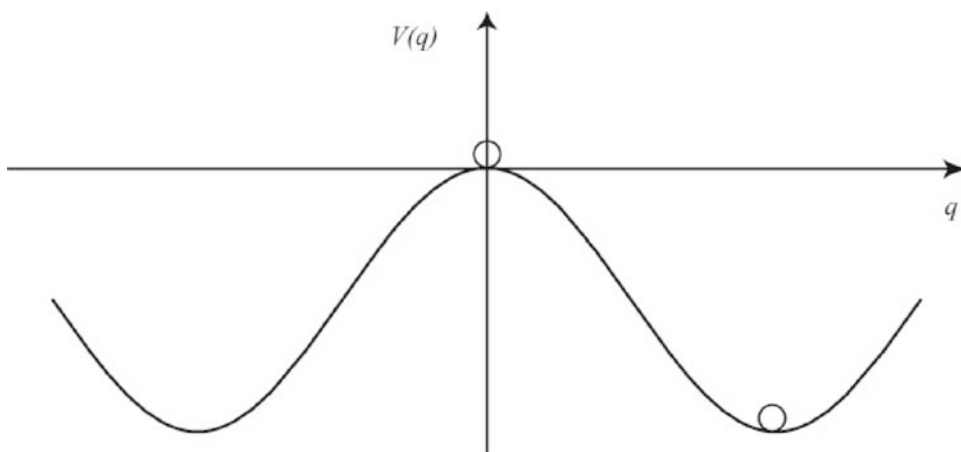
Figure 1.1: A ball initially in equilibrium rolls successively and randomly down to the minimum on the right, where it remains trapped if there are not sufficiently strong random fluctuations of the environment.

In the case of a bacterium, this work could be the movement of a certain cilium for swimming or flying in the direction (or in the opposite direction: in most simple case we only admit two possible motor outputs) of a certain chemical or temperature gradient. However, due to the difference between self and non–self, this choice will in general have some feedback consequence on the organism (here we have again entropic and energetic exchange, that is, stimuli are not subject to the organism's control): The choice will bring the organism to some energetic source or it will not. So far the choice is in accordance with the (inertial) self–maintenance of the organism, there are no reasons to move from the chosen minimum and the organism's choice is awarded. However, if the feedback is negative, the organism receives a stimulus that is somehow in disagreement with the chosen minimum.

When such a disagreement is present, from the "viewpoint" of the organism it faces a negative stimulus (a plus or minus big shock). However, from the "viewpoint" of the environment, the same phenomenon is a pure mechanical action. In general, when there is such a disagreement between self and non–self, at an abstract level two solutions are possible in order to reduce its amount. Either the non–self assimilates somehow the self. The most paradigmatic case is when the organism succumbs. In general, such assimilation is accomplished by brute, mechanical force, and has some disruption of the organism as a consequence. Obviously, the environment comprehends also individuals of other species and other individuals of the same species, and it can very well be that the organ-

ism dies because it is the object of some intelligent predation. However, it does not matter how intelligent this planification may be, the direct effect on the organism is always of mechanical type, so that, from the point of view of the organism any effect of the environment on it is of the same nature. Let me introduce an example about high organisms, even humans: somebody may plane very accurately and intelligently a homicide. However, at the end such a plane, in order to be effective, will be translated in some mechanical effect on the victim, for instance, a shot. This is the *direct* effect of this action on the victim.

The other possibility is that the organism tries to modify its status. In this latter case, the computational device of the organism through the shock is again set off of equilibrium, an autarchic random search is begun, and the cyclic process is run again. Such a process is evident during epigenesis [Waddington, 1974], but is a universal feature of any organism. The ultimate reason of such a new computation is to provide the organism with a suitable representation in order to somehow (even to a tiny extent) modify its environment by retroaction on it, that is, to accommodate the non–self to the self (see [Baldwin, 1894, Baldwin, 1902]). When speaking of representation, it is not necessary to think at something especially complicated: for instance, Gallistel [Gallistel, 1990] has shown that a simple oscillatory device in a unicellular organism can provide a rudimental representation of time.

In other words, in general representations are not produced for picturing something but for being focussed on something, which is the target of the organism. Such an external target is the referent relative to the representation. That is, a representation is a representation of an organism *for* a referent [Peirce, 1894]; [Auletta, 2002] and [Auletta, 2005a].

When organisms become complex, impressive evidences of such behaviour can be found. The organism may even try to manipulate environmental effects for inducing changes on its conspecifics. I recall here, at ontogenetic level, *stigmergy*, that is, the indirect influence of an individual on one of its conspecifics through a certain environmental modification that can affect the latter [Bonabeau, 1999], and, at phylogenetic level, *niche construction*, that is, the way populations of organisms can establish feedback effects on their own evolution by carving out the environment according to their needs [Oyama, 2001].
In general, many intermediate situations between the extreme of a pure mechanical disruption of the organism and an innovative transformation of the environment are possible, and finally both aspects are always

present.

Supposing that the organism has some matching (it is always a matter of degree) with the external conditions, we say that the organism *shares* some information with its environment. In this case, according to the previous examination, we also say that the organism has some representation of the external environment. The technical tool for information sharing is mutual information, defined as the amount of entropy or disorder of the organism minus the conditional entropy of the organism on the environment, that is,

$$I(O:E) = S(O) - S(O|E) \,, \qquad (1.7)$$

where $S(O)$ is the entropy of the organism O and

$$S(O|E) = S(O,E) - S(E) \qquad (1.8)$$

is the conditional entropy of the organism relative to the environment E, that is the total joint entropy $S(O,E)$ of the organism and the environment minus the entropy $S(E)$ of the environment (the conditional entropy is intuitively the degree to which the order of the organism does not depend on the environment). It is important to stress that the mutual information is only a degree of matching and does not suppose any information transfer between environment and organism [Auletta, 2005b]. I recall that the hypothesis is that the organism processes information in an autarchic way and that only responds in an adequate way to a given stimulus. A world where such transfer were possible, would be a Lamarckian world, that is, a world where the organism's reactions are *directly* structured by the environment.

I stress here that the hypothesis of a membrane and of an autarchic information processing are strictly related. In fact, without such a membrane the computation would be dependent on the input (on the stimulus), that is, on the external physical conditions, and the output would be mechanically determined. This is one of the most important flaws of the artificial intelligence, and to a certain extent also of artificial life, a flaw that, surprisingly, these disciplines have in common with behaviourism. In fact, it is not the complexity in the input elaboration (eventually through hidden or intermediate computational unities) [Rumelhart, 1986] to be the decisive issue. Actually, also in robotics one tries to let pattern of activity emerge [Mataric, 1992, Hendriks-Jansen, 1996]: Robots, for instance, can act following environmental landmarks and slipping from the behaviour specified by a

landmark into a behaviour specified by the next, rather than travelling from one landmark to another. However, this does not supply for the most important feature of living beings: Error correction. The separation between self and non–self and the autonomy of the computational process provide for error correction, which here can be seen as an optimization process in which the choice will be maintained as far as it is not too much in contrast with the stimuli (the possible suitable choices constitute an equivalence class). Indeed, in order to have error correction we must have error, and we can have error only if the two systems, self and non–self, are independent. If they do not be, we could have no possible adaptation of the organism to its environment.

Any new stimulus represents more or less a negative feedback for the organism. Letting again aside the case in which the organism dies, each stimulus determine some partial correction (or at least the attempt at correcting) through which the organism try to assimilate the external environment to itself. However, if the net effect of each stimulus were only to partially modify the computational path and therefore the final response of the organism, we would again make use, though in a more sophisticated way, of the old idea according to which the output is a function of the input. However, this is not the only organism's reaction. It also tries to efface the effects of a shocking stimulus and therefore to come back to a stand–by situation. In this way, it tries to make reversible the effects of the stimulus. This is accomplished in two ways: By modifying the environment (through some external action that eventually has an indirect effect on the organism itself), and by incorporating the new representation in the net of the already tested representations. This behaviour is the internal counterpart of the environment's modification, and its aim is to reduce the "novelty" of the new representation. Without this latter action, we could not satisfy the Landauer–Bennett theorem, and therefore we could not assure the autarchy of the organism.

An evidence of this reversible anti–feedback can be found in higher organisms, especially in their dreaming activity.
Atlan [Atlan, 1972, Atlan, 1974] understood very well that, when dreaming, one recreates a state where all initial association that progressively had become forbidden is once again allowed. Obviously, this process can never be total, since, on the one hand, by effacing all mutual information with the environment one would never learn, and this with high unadaptive effects, and, on the other hand, because any shock leaves always some trace: this is the price to pay for the partial openess of the organism. Another evidence could come from recent studies

about the way rats fix they spatial memories during rest periods (see
[Foster and Wilson, 2006]): They replay the sequence in a reverse order.

What happens in the majority of the cases is that, in its effort to
eliminate the effects of an environmental feedback and therefore to re-
store its initial state, the organism integrates with more or less success
this new stimulus in its previous representational net. In other words,
we have a dynamical process of integration of two opposite forces, whose
result is the reduction of distance not only between representation and
stimulus but also between old representation and new response. For this
reason, Hebb [Hebb, 1949, 111], quoting the words of Woodworth, says
that all perceiving is *schema with correction*. Or, in the words of Wal-
ter Freeman [Freeman, 1995, 100] on higher brain activity, a "change
constitutes a trajectory in cortical state space, which never return ex-
actly to a prior state, but returns ... sufficiently close to the prior state
that cortical output places a target of the transmission into the same
basin of attraction as did the prior output". This dynamical, smoothing,
integration process is what in higher organisms is called *interpretation*
and is perhaps the biological basis of any intelligent behaviour. This
distinction between stimulus, on the one hand, and its integration in
a dynamical whole, *i.e.* its interpretation, on the other, has a neural
basis, at least in mammals: It could be interpreted as a distinction be-
tween microscopic patterns of activity, which concern few neurons, are
spatially and temporally localized, and are stimulus–locked, and macro-
scopic, global, spatial–temporal patterns, which are distributed over the
entire sensory cortex involved and are directed to the meaning of the
stimulus for the organism [Freeman, 1995, 59].

For all these reasons, we should correct the use of the term *random
choice*. It is evident that with a certain (ontogenetic or phylogenetic)
history of the organism, more and more regularities come out. Certain
choices, if awarded, become habits. Moreover, when the organisms are
growingly complex, a network of different sorts of regularities becomes
possible, so that the choice is no longer random [Ellis, 2004]. To a cer-
tain extent it is neither for very rudimental organisms because already
here there are a lot of different, at least physical, constraints. However,
it remains true that any acquired regularity is always tested against a
certain environment, and in this way the procedure remain inductive
(open) as far as such a regularity can always be disproved, and to a
certain extent will be too. If the stimulus represents a problem for
the organism which requires some genuine new answer (a new choice)
it would be a case of what Peirce [Peirce, 1886], [Peirce, 1878] called

abduction [Auletta, 2005a]. In this process of optimization of the organism's response, when a specific reaction or action is reinforced and optimized more and more, it will become to a certain extent the automatized response of an organism to a class of (equivalent) stimuli. In this case, this response will be selected. In other words, selection is in general a process in which a rather indefinite response becomes more determined, and therefore also more stable. We have several evidences of such a behaviour for higher brains (see [Edelman, 1992] and [Edelman and Tononi, 2000]). This also means that, ascending in the evolutionary ladder, higher and higher organisms are necessarily open to an increasing variety of different stimuli. A bacterium is open to few stimuli. In other words, a high organism is less close than a unicellular one is. However, there are still mechanisms of control: they become rather indirect.

Obviously, the steps above indicated (computational process–choice–action–stimulus–new computational process) may not be necessarily executed in succession and by the organism as a whole. Actually, there can be partially autonomous subsystems, and many solutions are possible. This will however change nothing fundamental.

Resuming, an organism, at the most basic level, can be understood as an autonomous information–processing device that is in a second step confronted with an external stimulus. Its action tries to overcome to a certain extent the gulf between the result of its autarchic computation and the stimulus as well as between this result and the new response.