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ARTIFICIAL INTELLIGENCE AND NATURAL INTELLIGENCE:
AN HISTORICAL AND CRITICAL APPROACH*

The great Hellenistic engineer Hero of Alexandria illustrates through several examples in his *Pneumatica* and *Automata*,¹ the general regulation mechanism characteristic of every automatic device and practically known since pre-Roman times. According to it, if something happens in a certain direction in such devices, for example the shutting or the opening of a door, the opposite movement will automatically take place. Of course, this fact will be caused by some physical agent, as for example the mechanical tension of a spring or the moving power of steam, which determines the reaction or counteraction to the initial movement, and then an appearance of automatism, as in Hero's *eolipila* (illustrated in his *Pneumatica*, 2) or in the carrillon mechanism invented by Hero himself, and illustrated in his *Automata*, 1 and 2.

Incidentally, as it is well known, the main purposes of such automata until modern times were religious devotion or amusement, apart from the water clocks of the hellenistic period due, among others, to Hero himself, Ctesibius and Philo, and the mechanical clocks since mediaeval times, which had in fact more utilitarian goals. Anyway, to restate an initial situation spontaneously was the main feature of such automatic devices. So, in the mediaeval period the fall of a weight in mechanical falling weight clocks counteracts the lifting up of the weight, which winds up the clock and makes it go. However, in this last case, we have a new element of automatic control, previously almost ignored and now, to be true, only implicitly and practically known. It is the feedback mechanism already implicit in the working of mechanical falling weight clocks. If the weight naturally accelerates its falling speed (which is the expected counteraction to the winding up of the clock, caused by the force of gravity),

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¹ Cp. F. Klemm, *Technik, eine Geschichte ihrer Probleme*, Karl Alber, Freiburg-München 1954.

the clock naturally loses its motion uniformity and then it is no longer regular. But the acceleration itself of the falling speed in the clock increases the relenting contact between the reel where the rope hanging up the falling weight is wrapped round and an oscillating bar in touch with it inside the clock (the "foliot"). Then, this variable contact due to the acceleration itself of the falling body succeeds in counteracting this acceleration. Here we have a clear instance of negative feedback counteracting the spontaneous acceleration of an automatic mechanism such as a clock in order to make it work regularly.²

In more modern times, we have many examples of this new regulating principle, applied both to amusement and to economic goals, that is, for example, both to the automatic toys of the great French artisan Vaucanson,³ made for the pleasure of the French aristocracy and intelligentsia, and to the steam engine improved by J. Watt in the second half of the XVIIIth century for economic purposes. In particular, in Watt's steam engine, the flow itself of steam in excess puts into action a valve shutting the access of steam into the cylinder, in order to reduce the spontaneous waste of power due to the flow of steam.⁴

However, in spite of the widespread application of the feedback principle, we have—strange enough at first sight—no clear-cut reflection on the principle before J. C. Maxwell's paper "On Governors" of 1867, which finally inaugurates the science of cybernetics.⁵ This was in fact the first explicit theoretical and physico-mathematical statement of the feedback principle in terms of structural stability of some physical systems, that is self-regulating systems which preserve their structure by the operation of the feedback principle. In fact, this principle makes it possible to preserve the regular motion of the system in spite of local variations or fluctuations. When Maxwell inaugurated cybernetics in these terms, he was certainly influenced by the then dominant search for general equilibrium through fluctuations which is characteristic of the second half of the XIXth century's Europe, in science as well as in society. The search for general equilibrium and stability is for example evident in the so-called neo-classical economic theory⁶ as well as in physics, for example in the attempt made by Maxwell himself and L. Boltzmann to reduce thermodynamical irreversibility to dynamical reversibility.⁷ In my opinion, this general trend is linked to the search for a better use and control of the human element in the new industrial system through both the regulation of market and the regular and more efficient

² Cp. Carlo M. Cipolla, *Clocks and Culture 1300—1700*, London, Collins, 1967, and J. Attali, *Histoire du temps*, Fayard, Paris, 1983.

³ Cp. A. Loyré, *Dal mondo del pressappoco all' universo di precisione*, Torino, Einaudi, 1967.

⁴ Cp. Donald S. L. Cardwell, *From Watt to Clausius: the Rise of Thermodynamics in the Early Industrial Age*, London, Heinemann, 1971.

⁵ Reproduced in: J. Clerk Maxwell, *Scientific Papers*, Cambridge, 1890.

⁶ Cp. L. Walras, *Teoria matematica della ricchezza sociale*, Torino, UTET, 1878.

⁷ Cp. S. Brush, *The Kind of Motion We Call Heat*, North Holland, 1976.

functioning of machines. The explicit knowledge and application of the feedback principle, allowing a certain capability of automatic self-regulation to mechanisms, was of course useful to the purpose of reducing the dependence of machines on the arbitrary behaviour of labour. Now, as it had such an immediate purpose, Maxwell's paper on governors exemplifies the feedback principle with mechanical and electric apparatuses, but does not speak at all of the attempts to imitate human beings through automatic devices based on the feedback principle which had been made since pre-Roman times by the building of self-regulating automata. However, Maxwell's paper is the starting point not only of every theoretical, physico-mathematical reflection on the engineering of automatic control, but also of every further attempt to simulate human functions, even higher intellectual functions, through artificial devices, which is the other meaning of cybernetics, understood as the science of control in the animal and the machine, as the subtitle of N. Wiener's well-known book recites.⁸ This is quite obvious if we think of the autonomous control behaviour which is common both to the self-regulating mechanisms studied by Maxwell and to human brain is its operations for also human brain gains and increases its efficiency through a sort of autonomous control behaviour. In fact, mechanisms try to simulate the control behaviour of human brain in order to obtain the regular functioning of machines previously obtained by human intervention, and then to avoid depending too much on this human intervention. Many are now the hopes to imitate human brain entirely and not only partially by the application of the feedback principle in self-regulating mechanisms,⁹ but, even if these hopes have strong economical, political, philosophical and scientific roots, is this supposed reduction of natural intelligence to artificial intelligence through the application of the feedback principle really possible?

In order to discuss this question, it will be useful to compare Maxwell's with Norbert Wiener's cybernetics. What is then immediately evident is the more dynamical interpretation of the feedback principle by Wiener versus the more statical one by Maxwell. Wiener, the true re-founder of the science of cybernetics, underlines, in contrast with Maxwell, the capacity to learn of self-regulating machines.¹⁰ In his view, they not only react to inputs in order to preserve their uniform functioning, as in Maxwell's scheme, but can also modify and improve their functioning on the base of inputs and of their incorporated programmes. So, they can even modify the régime of their functioning on the base of new inputs. For example, they can modify, on the base of new data, the value of the speed to be preserved, in order to get more efficiency. There is no doubt that the wider and more elastic application of the

⁸ Cp. N. Wiener, *Cybernetics, or Control and Communication in the Animal and the Machine*, Cambridge, Mass., MIT Press, 1948.

⁹ Cp. D. Ritchie, *The Binary Brain*, Little, Brown and Co., Boston—Toronto 1984.

¹⁰ Cp. N. Wiener, *The Human Use of Human Beings*, Houghton Mifflin Co., Boston 1950.

feedback principle, understood as a true learning and not only a mere stabilization principle by Wiener represents the functioning of human brain more faithfully than Maxwell's purely homeostatic mechanism, but it is surely far from exhausting the possibility of human intelligence, its characteristic unpredictability. Wiener still thinks of human mind in terms of Pavlov's physiology, that is of changing adaptation to external stimuli.¹¹ In Wiener's view, if you know the external stimuli—inputs—and the possible replies of the organism registered in its memory—programmes—you can foresee how the feedback principle functions in different cases to obtain a better and better adaptation between stimuli and replies, in terms of applied rules of behaviour, even of rules changing according to the circumstances, to get better results. Therefore, Wiener was really frightened by the possibility, which he thought was imminent, of reducing human mind to machines by the application of the feedback principle, as we see in his book *God & Golem*.¹² But his fear was unjustified in logical and scientific terms, apart from considerations of practical realization. Of course, it is quite possible to reproduce many mental functions by the application of Wiener's scheme, and even, at least partially, to better and accelerate them. The development of logical machines and automatic devices aimed at imitating human functions, from computers to robots, is quite impressive today, but the claim to reproduce human mind completely by the feedback principle even in Wiener's wider and more elastic interpretation is in principle doomed to failure. Only few years before Wiener started to think of the reproducibility of human mind by machines, there was a crucial development in logic which definitely explained why such an attempt could never get a total, complete success. It was K. Gödel's theorem in 1931. It says that if you try to determine the truth of a logical system complex enough to contain at least all elementary arithmetics, you must pass from that system to another system more powerful than the previous one, that is a meta-system more general than it.¹³

Now, to reproduce a system like human mind scientifically implies to know it completely, that is to be able to determine its truth completely. Then, just when you attain the goal of reproducing the human mind, you extend your human mind to a level higher than the level of the human mind you reproduce, which is then no longer the entire human mind. This paradoxical situation indicates that not only Maxwell's, but also Wiener's model of feedback is unable to exhaust the potentialities of human intelligence, for even this last one is unable to pass from the simple collection and control of the inputs from the outer world according to predetermined rules, even changing and elastic, to unexpected and higher levels and rules not given in advance, levels of growing

¹¹ *Ibidem*, chap. III.

¹² Cp. N. Wiener, *God & Golem Inc. A Comment on Certain Points where Cybernetics Impugnes on Religion*, Cambridge, Mass., HIT Press, 1964.

¹³ E. Nagel and James R. Newman, *Gödel's Proof*, N. York, N. York University Press, 1958.

complexity never fully predetermined. The new rules belonging to the new levels are really unpredictable at the level of the known data and incorporated rules, and then cannot be obtained by any application of the feedback principle which operates at that level. They can be obtained only by the immersion of the known data and incorporated rules into a more complex and powerful logical system, which is able to change the rules and reinterpret the data in new ways without being at its turn reducible to them. As in logic a meta-system cannot be reduced to the system whose truth it determines, so is human intelligence unable to be entirely reduced to any artificial model it can make of itself, even if this model is a very intelligent and elastic one, as surely Wiener's was.