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The Ecological Approach to Information Processing

The World as Database

In the beginning was the mainframe computer: a large and somewhat ramshackle collection of boxes joined by wires. Then came the personal computer: a single, small box, which you could fit on your desk. At about the same time came functionalist conceptions of minds as "black boxes". And much fascination with the idea that the mind is a computer (and even, contrariwise, that the computer is a mind).

Now, however, the box conception of computers and minds is slowly losing its grip. Computers are connected together in gigantic networks; they move around; and, through Global Positioning Systems (GPS), they always know where they are. They are attached to digital video cameras and to meteorological and chemical and biological and medical and gamma ray sensors.[1] There are cognitive prostheses; wearable computers; computers you can hold in your hand; computers you can talk through; computers that can display the seismographic features of the terrain they are pointed at; computers that can display the vital signs of a patient you are examining who is a thousand miles away.

The European Media Lab in Heidelberg is testing tourism information services built into camera-sized computers which are at one and the same time ever-attentive tour guides, map displays, and cameras. You can point your computer/camera to the castle on the hill and ask it to read out the history of the castle; or display a map showing all non-smoking restaurants within walking distance; or inform you where in the vicinity of the castle you can buy cornflakes after 10 p.m. Computer/camera/sensor devices with even more powerful features are transforming the ways wars are fought and emergencies responded to. They are transforming com-

[1] O. Wolfson, "Moving Objects Information Management: The Database Challenge", *Proceedings of the 5th Workshop on Next Generation Information Technologies and Systems* (NGITS 2002), Caesarea, Israel, June 25–26, 2002.

puters themselves into entities that are, like human beings and other organisms, sensitive in different ways to their surroundings.

Knowledge Down a Wire

In the age of computers as boxes there arose the doctrine of methodological solipsism – also sometimes called "cognitivism" or "representationalism" (the differences do not matter here) – a doctrine that is commonly associated with the name of Fodor.[2] In order to understand a mind, on this doctrine – that is, in order to establish in scientific fashion the laws governing mental processes – you need to abstract away from all relations to any real-world objects toward which these mental processes might be directed. One should for methodological purposes assume, in other words, that solipsism is true, that the mind is a windowless monad. The parallel doctrine as applied to computers runs: computers are purely syntactic devices. Your computer deals, after all, not with *things* (castles, cornflakes), but with *strings* (with 1's and 0's); with what can be transmitted in the form of electrical impulses down a wire (or nerve). It is lacking all semantics.

Harry M. Collins tells the following story.[3] Imagine a 5-stone weakling whose brain has been loaded with all the knowledge of a champion tennis player. He goes to serve in his first match – Wham! – His arm falls off. The 5-stone weakling just doesn't have the bone structure or muscular development to serve that hard.

There are, clearly, different types of knowledge/ability/skill, only some of which are a matter of what can be transferred simply by passing signals down a wire from one brain (or computer) to another. Sometimes it is the *body* (the hardware) which knows. Sometimes it is the *world* (the environment) which knows. Your GPS device knows its location, not because of the impulses running through its wiring, and not because of the state of its hardware – but because it is at any given moment receiving quite specific signals from satellites and because these signals contain information to which it is sensitive in virtue of the precise location which it occupies in that moment. Human beings are sensitive to the information contained in other human beings' faces. Homing pigeons are sensitive to highly nuanced features of the earth's magnetic field. Hu-

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[2] See especially J. A. Fodor, "Methodological Solipsism Considered as a Research Strategy in Cognitive Psychology, *Behavioral and Brain Sciences* 3 (1980), pp. 63–109.

[3] "Humans, Machines, and the Structure of Knowledge", *SEHR*, vol. 4, no. 2: *Constructions of the Mind* (1995).

man beings who can read are sensitive to the astonishingly variable types of information contained in printed texts.

Information in the Light

As Andy Clark argues in his book *Being There: Putting Brain, Body and World Together Again*,[4] we know more than is contained in the hardware and software of our minds because we are able to engage in what Clark calls *epistemic action*. We manipulate Scrabble tiles in order to be able to use the re-arranged pieces as a basis for the activation of the brain's preconscious pattern-recognition abilities. We write one number above another in order to be able to carry out complex calculations using pen on paper by allowing our hands to perform manipulations with these numbers on a sort of automatic pilot. We act so as to simplify cognitive tasks *by leaning on the structures in our environment*. We rely on the external scaffolding of maps and models, of diagrams and traffic signs. Just as not all calculations are done inside the head, so not all thinking is done inside the head – because much of it involves an interaction with the world outside in ways which depend on the types of sensitivity the cognitive agent shows to his surroundings of the moment, which depend in turn on his goals, on what he is trying to achieve as an organism active in this world.

From Fodor to Gibson

From the perspective of Fodor's methodological solipsism the way to understand human cognition is to study the mind/brain in abstraction from its real-world environment (as if it were a hermetically sealed Cartesian ego). From the perspective of J. J. Gibson, Fodor's nemesis (for Gibson's time will come), the way to understand human cognition is to study the moving, acting human person as it exists in its real-world environment.[5] This means: taking account of how the human organism has evolved to fit into this real-world environment in such a way as to be sensitive to the information it contains (above all to those types of information which are relevant to survival).

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[4] Cambridge, MA: MIT Press, 1997.

[5] Barry Smith, "Truth and the Visual Field", in J. Petitot, F. J. Varela, B. Pachoud and J. M. Roy (eds.), *Naturalizing Phenomenology: Issues in Contemporary Phenomenology and Cognitive Science*, Stanford: Stanford University Press, 2000, pp. 317–329.

We are, from this perspective, like highly complex tuning forks – tuned through our batteries of sensors to the environment which surrounds us in highly specific ways. Gibson himself was a psychologist of perception. His most important work – which should be read in conjunction with the writings of Barker and Schoggen[6] – is entitled *The Ecological Approach to Visual Perception*.[7] The Fodorian holds that in order to understand information systems we should turn aside from the hardware and from the surrounding world in which this hardware is embedded, and study instead manipulations of syntactic strings. The Gibsonian holds that in order to understand information systems we should turn our attentions precisely to this hardware and taking account of the environment for which it was designed and built. We then discover that information systems, too (with their GPSs and their biological sensors), are like highly complex tuning forks – they have evolved (or better: were designed) to resonate in tune with certain highly specific surrounding environments, and their functioning is intelligible only to the degree that we take account of the ways in which they are embedded within such environments.

Computerized Agents

The world of computerized agents – of robots, avatars, webbots – is a world of computers situated in environments and capable of flexible, autonomous action within such environments, including interactions – such as communicating, negotiating, coordinating – with other agents, both human and non-human. The orthodox methodology for dealing with such computerized agents has been described by Rodney Brooks,[8] Director of the MIT Artificial Intelligence Laboratory, as the "SMPA view" – for Sense Model Plan Act as follows:

[6] P. Schoggen, *Behavior Settings: A Review and Extension of Roger G. Barker's Ecological Psychology*, Stanford, CA: Stanford University Press, 1989; H. Heft, *Ecological Psychology in Context: James Gibson, Roger Baker, and the Legacy of William James's Radical Empiricism*, Mahwah, NJ: Lawrence Erlbaum Associates, 2001.

[7] James J. Gibson, *The Ecological Approach to Visual Perception*, Boston: Houghton-Mifflin, 1979.

[8] See his papers "Intelligence Without Representation", *Artificial Intelligence Journal* 47 (1991), pp. 139–159, and "Intelligence Without Reason", *Proceedings of the 12th International Joint Conference on Artificial Intelligence*, Sydney, Australia, August 1991, pp. 569–595.

S: the agent first *senses* its environment through sensors
M: it then uses this data to build a *model* of the world
P: it then produces a *plan* to achieve goals
A: it then *acts* on this plan.

We are clearly once more inside a Fodorian perspective. Instead of relying on its surrounding environment, on the SMPA conception the agent builds an internal *model* of the world – an internal representation or copy – and it is to the latter that the agent's cognitive processes are directed.

In his own "Engineering Approach" to the problem of understanding and constructing computerized agents, in contrast, Brooks (like Gibson) lends very little weight to the role of representations or models. Rather, he takes his inspiration from evolutionary biology. In order to produce systems that interact directly with the world we should take as our starting-point simple organisms who have solved the problems of interacting with their surrounding physical environment in ways conducive to survival.

The Life (and Mind) of E. Coli

Consider for example the movement of the E. coli bacterium, which can best be described as a biased random walk.[9] In the default environment, which is marked by the absence of any survival-relevant stimulus, the cell simply wanders around, smoothly swimming by rotating its flagella counterclockwise. Such runs are terminated by chaotic events, called tumbles, when flagella rotate clockwise. Following a tumble, the cell begins a new run, picking a direction more or less at random. Sometimes however the cell encounters sugar – more precisely it encounters an increase in the density of a chemical attractant – to which its sensors have been attuned by natural selection. Those runs that happen to carry it up such a density gradient are then extended; those that happen to carry it down the gradient are not. Over time, therefore, the cell drifts in a favorable direction. Its life, if you like, is a life of *falling down sugar wells*.

[9] H. C. Berg, "A Physicist Looks at Bacterial Chemotaxis", *Cold Spring Harbor Symposia on Quantitative Biology* 53 (1988), pp. 1–9; Frederik Stjernfelt, "Biosemiotics and Formal Ontology", *Semiotica* 127 (1999), pp. 537–66; Bruce Alberts et al., *Molecular Biology of the Cell*, 4th edition, New York: Garland Science, 2002.

The bacterium is a single cell. Thus it does not have a multicelled nervous system. But it has receptor molecules acting as sensors and these influence the behavior of its highly complex machinery of movable flagella via a signal transduction system. Different receptors react to different stimuli, some to single oxygen molecules, some to much larger carbohydrate molecules (or to molecules – perhaps produced in the laboratory as anti-bacterial agents – which have an external structure which can *fool* the bacterium into thinking that it is dealing with carbohydrate molecules). E. coli bacteria react to differences in concentrations of sugar molecules with a behavior shift – as a dog reacts to the smelt trace of another animal.

The attribution of intentionality, as we can see, does not depend upon the existence of a nervous system. There is a difference between a purely chemical system, and a system that is at once chemical and biological. We can ascribe simple biological intentionality to a single, movable cell; all that is required is the existence of sensors, information mediation (automatic interpretation, if you like) and motor responses resulting in adaptable behavior.

Intelligence as Situatedness

Let us return now to Brooks' Engineering Approach to the construction of computerized agents. Where the bacterium has one single layer of activity, intelligent systems such as ourselves embody a number of distinct such layers, including our various batteries of sensors (perceptual systems), as well as systems for proprioception, and so on. From Brooks' perspective, now, we should conceive such layers (a) as operating independently of each other, (b) as connecting directly to the environment outside the system.

Each layer operates as a complete system that copes in real time with a changing environment. Each layer is a biological system that has evolved through interaction with the world outside, and it is this world outside which serves to unify the different layers together in such a way as to ensure that they become adjusted to each other mutually over time. For Brooks therefore, *an artificial system that mimics some of the features of biological intelligence must be a situated system.*

Humans (and other organisms) fix their beliefs as they attune themselves differently to different parts of the world in light of their successive experiences. As Brooks points out in his "Intelligence without Representation", organisms sometimes mark the world by placing traces which change what they will be confronted with in the future. Thus they do not have to carry all their memories around with them, because again: they can lean on the structures in the external environment; they can use *the marked-up world as crutch*.

The Ecological Approach to External Symbolic Memory Devices

For human organisms the marked-up world includes libraries, maps, price lists, traffic signs, science texts, border posts, restaurant menus, fences. We can now rephrase our formulation of the views developed by Gibson in his *Ecological Approach to Visual Perception* as follows. We are like multi-layered tuning forks – tuned to the environment which surrounds us. We have evolved in such a way as to be attuned to our environment on multiple levels, in part because we ourselves have created this world via what Lewontin calls "ecosystem engineering".[10] This means that we have evolved to resonate automatically and directly, not only to those features of our environment which are relevant for survival, but also to new features – of language, culture, of externalized memory – which we ourselves have put there.

In his *Origins of the Modern Mind*[11] Merlin Donald refers to a radical transition in the emergence of modern human culture, which occurred when humans began to construct elaborate symbolic systems ranging from cuneiforms, hieroglyphics, and ideograms to alphabetic languages and mathematics. From this point on, Donald argues, human biological memory becomes an inadequate vehicle for storing and processing our collective knowledge. Thus Donald sees the modern mind as being itself a hybrid structure built from vestiges of earlier biological stages together with new external symbolic memory devices.

Gibson's ecological approach can now be reformulated yet again in order to take account of Donald's insight. To understand cognition we should study the moving, acting organism as it exists in its real-world environment, but now taking account of the fact that for human organisms this is a social environment which includes records and traces of prior actions in the form of communication systems (languages), storage systems (libraries), transport systems (roads), as well as legal and financial and political systems of a range of different sorts. The attunement of dif-

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[10] Richard C. Lewontin, *The Triple Helix: Gene, Organism, and Environment*, Cambridge, MA: Harvard University Press, 2000.

[11] *Origins of the Modern Mind: Three Stages in the Evolution of Culture and Cognition*, Cambridge, MA: Harvard University Press, 1991.

ferent groups of specialists to these externalized symbolic memory devices then allows a range of different, new sorts of activities on the part of humankind, via a vast division of cognitive-ecological labour. Gibson talks of the environment as an array of affordances, where: "The affordances of the environment are what it offers the animal, what it provides or furnishes, either for good or evil." The environment of a commercial organism includes those affordance which we call prices. The environment of a lawyer includes those affordances which we call torts and malfeasances. The environment of a physician includes those affordances which we call symptoms and diseases on the part of his patients. The environment of a computer-aided geologist investigating viscoelastic flow includes those affordances which we call foreshock sequences and processes of earthquake nucleation. The realm of affordances, and thereby the world itself as a domain accessible to our direct cognition and action, becomes hereby expanded – not only because of the addition of ever new layers of external memory devices, but also because of the addition of ever new types of prosthetic sensors, which enable us to become attuned to ever new sorts of features in the environments by which we are engaged.[12]

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