Spectators or actors? Complex science and exploring open worlds

Stephen Read

> There is nothing that man is truly capable of dominating: for man everything is immediately too large or too small, too mixed or composed of successive layers that dissimulate in view what it would like to observe. Surely! Yet one thing and one thing alone is dominated by the gaze: it's a sheet of paper extended on a table or tacked onto a wall. The history of science and technology to a large degree tells of ruses which allow the world to be brought onto this paper surface. Then, yes, the mind dominates it and sees it. Nothing can be hidden, obfuscated or dissimulated.
>
> Bruno Latour[1]

Research and design

The question of research and design is not one of two activities, different in principle, that then need to be related to each other. What I will propose rather is that what we do (as scientists, as designers and indeed as ordinary people just going about our everyday business) is *make* the world around ourselves in the form of more or less complex representations. It is these representations that then come to define reality and the worlds in which we intervene or act. I will first summarize what I see as a science of today (Stengers & Prigogine); then talk about representation, reality and world by way of construction and intervention (Hacking); about actors and spectators (Hacking); science as a local practice of the manipulation and creation of phenomena – and as a meeting of the different space-time frames of the phenomenon on the one hand and apparatus and actor/observer on the other (Stengers); modeling and simulation (Hacking and Stengers); and maps and images in science (Galison).[2] Science is an intervention in the world and the obtaining of results involves us in a complex construction and manipulation of the frames of reference of the phenomenon through our constructive and practical making of representations, models or images – think here of experimental practice and the *design* of experiments. Both research and design are about creating situated constructions or interventions in the world and have no fundamental (or even interesting) points of difference.

One of the questions this paper will try to expand on is the one which asks whether we are, as scientists and indeed as ordinary people, actors in or spectators of the events we try to understand.[3] This question becomes

---

[1] Bruno Latour (1985), “Les 'Vues' de l'Esprit: une introduction à l'anthropologie des sciences et des techniques” in: *Culture Technique*, no.14, pp.5-29 p. 21. Available on Bruno Latour’s website.

[2] My major references are: Ian Hacking (1983), *Representing and Intervening*, Cambridge University Press, Cambridge (hereinafter H); Isabelle Stengers, partly with Ilya Prigogine (1997), *Power and Invention*, University of Minnesota Press, Minneapolis (hereinafter S), and; Peter Galison (2002), “Images scatter into data. Data scatter into images” in: Bruno Latour & Peter Wiebel, eds., *Iconoclash*, MIT Press, Cambridge, Mass. (hereinafter G).

[3] S p. 43

interesting in the first place in that in asking it we raise another question – that of ‘the critical’ – which places the rational human subject at the center of things (Kant), versus ‘the constructive’, which attempts to escape the ‘Kantian tribunal’ by considering, or trying to consider, “the place of the thing judged or criticized”[4] (Whitehead, Dewey, etc. down to Hacking, Stengers etc.). The question is one that brings *doing* to the center in place of thinking, and that reintroduces, or rather acknowledges once more, risk and the possibility of error in a scientific process whose progress and outcome are not guaranteed (certainly not by any “royal” methodological “road to the truth”), but whose furthering is worth the effort and the risk of failure anyway. And what this question addresses underneath these more overt questions is whether we as people (ordinary people or scientists) *receive* our worlds by way of a mentality separate from the materiality of the world, or *construct* them at some basic and integral level – and do we in fact find our way in an uncertain world by reflection or by action? The second position places originary emphasis on our own *production* of the world we live in by way of conceptual and constructive work, and makes us creative explorers of simultaneously real-and-constructed worlds, probing, making and remaking worlds from the inside, as opposed to being god-like creatures, surveying and passing judgment on reality from the ‘outside’.

> The critic’s ultimate goal is to escape all possible criticism, to be beyond criticism. He looks over everyone else’s shoulder and persuades everyone that he has no shoulder. That he has no heart. He asks all the questions so that none can be asked of him. …
>
> [W]hat would you call the only person who could be imagined as looking over everyone’s shoulder, without having a shoulder of his own? God. So, beware of philosophies that put he who practices them in the august position of always being right, of always being the wisest, the most intelligent, and the strongest. These philosophies always and eternally come down to strategies of war.
>
> You wanted to talk about an ethic. Mine forbids me from playing that particular game. I willingly admit, before I begin, that I am not always right. This irenicism is the fundamental condition of intellectual honesty. …
>
> It is better to do than to judge, to produce than to evaluate. Or, rather, it is in mining coal that one learns if it is grey or black. It is better to create than to criticize, to invent than to classify copies.[5]

I am asking this question in relation to the activity of scientists (or again of ordinary people) trying to understand and know the world around them. And this also and necessarily means understanding and knowing it in terms that are relevant to the concerns we have about it. There is no such thing as a ‘pure’ science, free of the situated and historical dispositions of the enquirers (I will come back to this later), and one of those concerns today, stated in a very general way, is ‘change’. We have already taught ourselves how to deal with static things, and with things that change in regular (and reversible) ways around points of equilibrium, but find ourselves still puzzled and caught out by the objects and processes in our world that change (and even produce) in

---

[4] Michel Serres & Bruno Latour (1995), Conversations on Science, Culture and Time, University of Michigan Press, Ann Arbor. p. 128
[5] ibid. p. 133-6

highly complex (and irreversible) ways, and in ways 'far from equilibrium'. Living things are an example of the type of things I am talking about but there are other things in the world (cities for example), which are not by our everyday definitions living, but which also change in ways which produce, out of themselves, new or transformed things.

Complex (open) science

Another question which determines the nature of the main question we are asking is a very old one indeed. It is also the famous one Einstein raised when he asked whether or not God played dice. Actually this was not so much a question for him as a starting point: he firmly believed that God did not play dice; that nature was by no means aleatory. The answer to the questions I raise above may perhaps best be first approached through this question – the one which asks whether the regular, foreseeable and reproducible behaviors we encounter in the world are a product of fortuitous chance, a result of atoms or forces clattering together in unpredictable ways; or, is there some kind of law, or set of laws intrinsic to nature, that comes first? Can we, in other words, as a starting position, define the forces in nature in terms of a lawful behavior? or, is there a basic lawlessness which agitates the world at some original level, and which nevertheless produces order? This question is at least as old as the Greeks who speculated about whether the change, whereby things are born and die, was imposed from the outside on matter that simply submitted, or was matter itself in some way the author of its own destiny. The lawful universe has an original model in the Aristotelian celestial system, one which was taken up and developed further by Galileo, Kepler and Newton. This was a system perfectly regular and ideal, which could be predicted (and post-dicted) to eternity. But while this perfectly regular system began after Newton to invade our sublunar world, for Aristotle, things were clear: the perfect celestial order stopped at the moon, and was not applicable to the ordinary everyday world around us. He and the pre-Socratics believed this everyday world was fundamentally 'organic' in the sense that things spontaneously and autonomously organized themselves into existence by way of processes inherent to their materiality.

The development of Newtonian dynamics from the seventeenth century was understood quite explicitly at the time as a challenge to this 'organic' or 'biological' model of things. Then the development and success of dynamics convinced many that what we were seeing was a triumph of the view that matter is inherently passive and subject to universal laws that affect it, in effect, from the 'outside'. It appeared that an eternal (therefore timeless) clockwork world of the celestial spheres was trickling down to us, in layered and complicated ways of course, but in a way that nonetheless preserved this essential feature of the reduction of all phenomena to a set of eternal laws. It was precisely this trickling down of the celestial order into other orders of existence that Einstein was defending with his famous statement. Henri Bergson famously took issue with him on this point, but failed to shift the idea of a timeless universe from the center of thinking in the natural sciences, where it still dominates today (vis. Stephen Hawking's faith that there exists at the end of the road of scientific enquiry a 'theory of everything'). Ilya Prigogine and Isabelle Stengers are notable dissenters to this view: they make the point that the 'disenchantment' of the world Max Weber saw as the effect of science and especially physics on our modern world, is nothing other than an effect of this '*deification'* of the world – of the attributing to nature of an order that originates in some 'celestial' and eternal realm beyond itself. "The world of dynamics is a 'divine' world untouched by time and from which the birth and death of things is forever excluded'"[6]

But we can also see that in a strange way, it may have been the way that the question was posed and presented by way of the mathematical 'idealization' of experimental evidence that gave the timeless and 'celestial' view its power in the first place! By entertaining the thought we might obtain access to a universal 'nature of all things', we began to imagine we could see the traces of this 'divine' nature in the highly controlled and artificial processes of experimentation and mathematical representation we set up to observe them. We took what are after all gross macro-scale aggregates of highly complex micro-scaled effects (at whatever scale one operates there is always another which exists as a 'micro' to it), strategically minimizing and selectively ignoring many 'extraneous' factors and messages nature was throwing at us, and began to imagine that the whole of existence could be absorbed into a total lawful 'system of the world' which left nothing outside itself. The factors found in experiment and experience which didn't fit (which were extra to the system in other words) we took as being 'noise' or 'residue' or 'excess', needing for now to be screened out or controlled so that we could see clearly the timeless order underlying it all. This 'noise' or 'residue' would eventually, we were convinced, be reincorporated into the system as the system ultimately incorporated to itself every scale and grain of existence.

The objects of dynamics could therefore, we imagined, eventually be completely understood. Defining any point in the system would in fact allow one to know all the rest with absolute certainty: to know absolutely its future and its past to the limits of eternity. A consequence of such a system is that it would by definition exclude the describer of such a state of affairs – there is no place in it for anything but the 'optimal description' where every moment and every event are determined in relation to every other.[7] The passivity of matter in the face of law, and therefore also its manipulability in terms of the (potentially absolute) knowledge we have of its states, became the dominant motif of the further development of science. In fact the way we posed the question (in terms of the ultimate universality of order) and the way the question was answered (in the way experimental science controlled and strategically minimized that pesky and

---

[6] S p. 34

[7] Examples are many, also in our own discipline: See Guyt & Hulsbergen's "Urban Programming Research" (in: de Jong & van der Voordt, eds. *Ways to Study and Research*, Delft, 2002) which assumes an ahistoricity and passivity of the urban 'object' which we can see is at precisely the point where the 'crisis of planning' has emerged. This is not to say of course that UPR is useless, only that it is partial and limited in its understanding of the object on which it acts and that it may be vitally important to understand these limitations (and where other approaches may supplement it). It is possible of course, without this broadening of perspective, to fall into the error of seeing the absence of the urban object as being something 'natural' and 'of the world' rather than as an artifact of the particular point of view.

inconvenient ‘noise’ or ‘residue’) forged the link between science as a search for knowledge, and technique, born in the laboratory, to manipulate and order the world to our own ends. Knowledge and technique became tied in a bond which has come to define our particular modern way of understanding the world.

This is not intended to say that the sciences are nothing but a project of mastery, as they have so often been portrayed in the postmodern critique. What I intend to say is that we need to beware of a view which sees a necessity, derived from its origin in the absolute, in a particular path of scientific progress. There are ultimately no necessities of the method or progress of science, nothing in the end to make us believe it forms or will form a closed and self-completing system. The trick Kurt Gödel performed on Whitehead’s & Russell’s system of mathematics can be extrapolated to all our other systems as well. The pathways of research are in no way determined by a logic internal to an absolute ‘scientific’ knowledge of the world. Stengers and Prigogine recount, using the example of thermodynamics, the way the transformations of our interests and the things which concern us as a society and as individuals have deeply affected the questions about the world we have considered decisive, as well as the shape of the science of those questions. These human and societal concerns have molded a landscape of scientific disciplines and practices rather than the sciences themselves. “Because it was a question of modifying the scope of concepts, of shifting problems into a new landscape, of introducing questions that drastically change the definition of disciplines, in short, because it was a matter of inscribing within science the urgency of new preoccupations, this opening took multiple and often sly paths.”[8]

The diffusion of heat energy according to Fourier’s Law was initially understood in relation to the use of heat and its transformation into motion in engines. Heat diffusion was understood therefore as ‘waste’ and the Carnot cycle, from which the laws of thermodynamics would be formulated, can be seen as a set of devices that seek to minimize irreversible conduction. As it happened, the irreversibility found in heat dissipation was a contradiction of the ‘eternal law’ of the heavenly bodies, and for the first time therefore, *time* made its appearance in modern science as a mathematization. But while irreversibility could not be avoided here, the way entropy and thermodynamics was set up was to preserve as far as possible the basic prejudice of dynamics – that the world should be reducible to a reversible and eternal (timeless) system. An idealized ‘entropy’ was concocted which was organized around equilibrium states and described perfectly reversible conversions between calorific and mechanical energies. These ideas served a particular and historical interest in the use of this conversion to power the nineteenth century industrial machine. A shift in interest and concern – to the problem of biological growth – and it was noted that natural processes increase entropy. Suddenly entropy became something not so much to be controlled and restricted in its increase, as valued in its link to these natural processes and their production of growth and novelty. It is a well-known joke in non-reversible thermodynamics circles that the only biological process dynamics was ever able to describe adequately was death: here suddenly, in a shift of perspective, we find a factor negatively associated with

[8] S p. 36

the inevitable heat-death of the universe, suddenly becoming valued as positive in its association with life and change and the coming into being of new things.[9]

The opening of thermodynamics into systems not cut off artificially from the world was a product of the desire to engage a world peopled by beings capable of evolving and innovating. It was found that the circulations through certain physicochemical systems, keeping them away from equilibrium, could support processes of spontaneous self-organization. Where the doctrine of universal law stops therefore, we see the constructive role of time begin: we enter “the domain where collective behaviors are born and die, or transform themselves into a singular history that weaves together the uncertainty of fluctuations and the necessity of laws.”[10]

> For the first time, it is not the manipulable that is subjected to analysis but rather that which, by definition, escapes manipulation or can only be subjected to it with ruses and losses. And thus physics recognized that dynamics – which describes nature as obedient and controllable in its being – only corresponds to a particular case. In thermodynamics, the controllable character is not natural but the product of artifice; the tendency to escape from domination manifests the intrinsic activity of nature. To nature all states are not alike.[11]

Stengers and Prigogine note also how the indeterminacy of molecular motion, known already in the nineteenth century, was alternately understood as ‘intrinsic’ and ‘epistemological’. In other words physicists were not sure if the inability to predict the behavior of molecules had to do with the molecules or simply with our inadequate knowledge of them – if it was a fundamental character of nature or a failure at the level of epistemology. Then, according to Stengers and Prigogine, indeterminacy was transmuted into opposition in the interpretation of the quantum mechanical formalism. Today we begin to understand that ‘points of singularity’ – where properties and actions become unpredictable – are everywhere, in every region of the phase space of every type of phenomenon. We see that the trajectories of dynamics are idealizations; in the real world we are looking at divergent trajectories of highly unpredictable elements that may nevertheless become ‘bound up’ with each other in the most intimate of ways. We are looking in fact at statistical artifacts whose microscopic constituents in no way relinquish their right to act differently – neither, for that matter, does anything but probability guarantee the collective of elements any continuity of its way of behaving as a combination.

> At both the macroscopic and microscopic levels, the sciences of nature are thus liberated from a narrow conception of objective reality, which believes that it must in principle deny novelty and diversity in the name of an unchanging universal law. They are freed from a fascination that represented rationality as closed and

---

[9] Even Norbert Wiener, the ‘father of cybernetics’ still associated entropy and ‘noise’ with inefficiency, and saw it as “nature’s tendency to degrade the organized and to destroy the meaningful” (Wiener, *The Human Use of Human Beings: Cybernetics and Society*, Boston, 1950). It was Gregory Bateson who understood best, of all the cyberneticians, how ‘noise’ was not the death of the universe at all, but rather the only possible source of novelty and change.
[10] S p. 38
[11] S p. 37

> knowledge as in the process of completion. They are from now on open to unpredictability, no longer viewed in terms of an imperfect knowledge, or of insufficient control. Thus they are open to a dialogue with a nature that cannot be dominated by a theoretical gaze, *but must be explored*, with an open world *to which we belong, in whose construction we participate*.[12]

Representation

An *a priori* ideal defined the celestial realm of Aristotle as it did indeed that of Newton. For the Greeks this ideal was expressed in ideal forms so that the movements of the planets were understood to be perfect circles. The celestial universe was a system of perfect geometric rationality with this rational pattern imposed *a priori* over it. The 'breaking of the circle' spoken of by historians of science refers to the discovery by Kepler that the circles were not perfect but elliptical. Mathematics changed with Kepler from being a means of simulating the movements of the spheres to being a research tool, and we could even understand it to be here that we find the opening of the very first chinks in a 'crisis of rationality'– and then see these chinks deepen as Newton proposed his mathematical formalization of gravitation that started from the bizarre position that an insubstantial force, acting at a distance and through a vacuum, was responsible for the shapes of planetary orbits. We may indeed, if we are so inclined, read all of this as the beginning of a process of the erosion of a bond between rationality and natural process. It was remember, by way of this bond that it was understood that we could overview and judge the world of phenomena in the name of a normative (rational) ideal. It marked also a moment in the history of science when the power of the mathematical description asserted itself – because of course Newton's formulation *worked*, and scientists were persuaded to overlook the phenomenological conundrum the formulation created. The doctrine of 'sufficient reason' found its expression in the equals sign in the mathematical formalization. But what science was trying most of all to do was maintain a power of our *representation* of things by way of an ideal (by now structural-mathematical rather than geometric), and by way of a timeless normativity. And it was trying to do this comprehensively: in the end this ideal and its comprehensiveness mattered more than the conundrums created at the level of phenomenological explanation about forces at distances. The point was there was supposed to be a *truth* revealed *in the formula* which had to do with equivalence between an ideal (divine, rational, mental) world and matters in the real world. The more general formulation of this principle by Locke is well known.

Kant's 'representation' was a 'placing before the mind' that doesn't say straightforwardly that there is a correspondence, more or less true, between structures of thought and what exists in the world 'in itself'. That was 'transcendental realism' and was Locke's position. Kant was more sophisticated, and he tried to resolve this against the 'empirical idealism' of Berkley for example. He granted, on the one hand, "the objective validity of space, in respect of whatever can be presented to us outwardly as object", but asserted on the other that space "is nothing at all … once we withdraw … its limitation to possible experience and so look upon it as something that underlies

---

[12] S p. 40 (my emphases)

things in themselves."[13] He proposed therefore not the absolute space of Newton, but not either the relative space of Leibnitz, rather: that space and time are preconditions for the perception of something as an object. Space and time are not empirical facts in themselves but we may experimentally determine the spatio-temporal relationships of objects within the framework of space and time. The world for Kant was "only a species of representations (intuition) which are called external, not as standing in relation to objects in themselves external, but because they relate perceptions to the space in which all things are external to one another, while yet the space itself is within us." It is therefore essential to Kant's point of view that objects are constituted within a scheme that organizes the relations between them and that what we understand as 'true' or 'real' is what exists within this scheme.[14]

Kant resolves the conflict between the absolute and the relative in this way precisely because it was understood as important to preserve, while acknowledging the subject, the relation between nature and the celestial normativity science wanted to impose on it. We could see it as a construction that preserved the best bits of both absolute and relative viewpoints (and those of the empiricists and the idealists) – *along with the celestial ideal* – and allowed things to go forward as normal. So much that has happened since depends on this 'resolution', but a consequence, according to Ian Hacking, is that by considering knowledge as a *representation* of nature we have put ourselves in the position of being unable to escape from representation and "hook-up again with the real world." We have come to accept the Kantian 'resolution', and to accept as an absolute given (also and particularly in postmodernism) that we are completely and inescapably locked into representation, and hence into some version of idealism.[15] And we can see again how we could understand the idea of representation, at least in this form, as having been invented precisely to preserve the ideal of celestial perfection in the order of things around us. Error, accident and novelty – indeed any form of becoming (or emergence) – has

---

[13] Kant (1923), Critique of Pure Reason, London. p. 72; H p. 97

[14] Ian Hacking will argue on the other hand that nature does not dictate any organizing scheme to us, and different schemes need have no connection to one another. "[Nelson Goodman] shows that whenever we reach any general conclusion on the basis of evidence about … instances, we could by the same rules of inference, but with different preferences in classification, reach an opposite conclusion… there is no general solution to his new riddle. Its scope goes far beyond induction and other trifling modes of reason. It confirms his doctrine… that we can and do inhabit many worlds" (Hacking, "World-Making by Kind-Making: Child Abuse for Example" in: M. Douglas and D. Hull eds., *How Classification Works*. Edinburgh, 1992. p. 181). No one organizing scheme can, in other words, claim primacy; different organizing schemes need not be compatible with or reducible to one another. Hence, different 'worlds' thrive and grow – and yet, according to Hacking tolerating a pluralism of worlds does not sanction sacrificing rigor. "A broad mind is no substitute for hard work." (Goodman, Ways of Worldmaking, Indianapolis, 1978. p. 21)

[15] Think in more recent times of Wittgenstein and the 'linguistic turn'; think of phenomenology

been taken out of the world and located instead in our representations and in our subjectivity.[16]

More recently others as well, arguing from a philosophical-historical-anthropological viewpoint, have challenged Kant's resolution, arguing that its terms are entirely misplaced. Hacking for example reverses the terms of the problem: he proposes (speculatively admittedly) that we are anthropologically inclined to be representers – in the sense that we are predisposed as a species to make *likenesses* of things. He points to the enormous history of such representations and their clear significance to people down the ages. He argues further that notions like 'truth' and 'reality' could only really become interesting as *questions* in relation to these likenesses: the question would simply never have arisen before there were likenesses whose veracity could be argued about.

> The first peculiarly human invention is representation. Once there is a practice of representing, a second-order concept follows in train. This is the concept of reality, a concept which has content only when there are first order representations. … First there is this human thing, the making of representations. Then there was the judging of representations as real or unreal, true or false, faithful or unfaithful. Finally comes the world, not first but second, third or fourth… The world has an excellent place, even if not a first one. It was found by conceptualizing the real as an attribute of representations.[17]

Suddenly we find ourselves in a completely different ball-park! It seems true indeed that we don't question the reality of most of the everyday stuff we see around ourselves and interact with. We don't think much about the 'representation' of this stuff either or whether or not it is *really* there. We take most reality quite for granted, as according to Hacking we should: there *is* a difference between horses and grass, between flesh and horseflesh, which we know and understand as real without talking or agonizing much about it. The question only arises in relation to more complicated representational likenesses we make of and about the world, and it happens *in their circulation in a public sphere*. Kant's 'representation' is all private and all internal; it goes on inside the head and is famously inaccessible to others. The kinds of representation Hacking is talking about are public and *external*, and are open to argument and to dispute, and it is precisely *here* that people begin to talk about reality and truth or the lack thereof! Of course there is a reality of the world before we get to this representation and this reality – the point is we *conceptualize* reality after we have something whose reality we can raise as a question and advocate or dispute. We dispute 'realities' and propose others, and it is on the basis of different *representations* of those 'realities' therefore that different 'versions' (to use Nelson Goodman's heavily loaded word) of 'reality' and of 'world' may arise.

---

[16] Here we can see again how postmodernism contains a confusion about the stakes and dualisms of modernism and is in fact a continuation of its deepest principles. The real postmodernists were people like Pierce, Dewey, Bergson and Whitehead, who understood that we had to escape idealisms altogether and get back to a materiality of things and the lifelike force of becoming and change.

[17] H p. 136

Ian Hacking points out one of the advantages of a notion of 'likeness' as opposed to one of 'truth'. 'Likeness' is not absolute, it is a relative term. But it is not in itself a relation; it sets *the terms* of the relation. "There is first of all likeness, and then likeness *to* something or other... There is no absurdity in thinking that there is a raw and unrefined notion of likeness springing up with the making of representations, and which, as people become more skilful in working with materials, engenders all sorts of different ways of noticing what is like what." We employ representations in other words to add layers and *versions* to our reality. These become in a sense forms of *visibility*, allowing us to see in new and surprising and revealing and potentially useful ways. But we see also in ways which challenge other ways of seeing. Much philosophy therefore, according to Hacking, mis-orders the relation between 'appearance', 'representation' and 'reality'. "Locke thought that we have appearance, then form mental representations and finally, seek reality. On the contrary, we make public representations, form the concept of reality, and, as systems of representation multiply, we become skeptics and form the idea of mere appearance." And: "As soon as what we would now call speculative physics had given us alternative pictures of reality, metaphysics was in place. Metaphysics is about criteria of reality. Metaphysics is intended to sort good systems of representation from bad ones. Metaphysics is put in place to sort representations when the only criteria for representations are supposed to be internal to representation itself."

> [T]he new science of the seventeenth century could supplant even organized religion and say that it was giving the true representation of the world. … All of that was fine until it began to be realized that there might be several ways to represent the same facts. … It is not only the artists of the 1870s and 1880s who are giving us new systems of representation called post-impressionism or whatever. … Whereas art learns to live with different modes of representation, [we see Heinrich] Hertz valiantly trying to find uniquely the right one for mechanics. None of the traditional values … values of prediction, explanation, simplicity, fertility, and so forth, quite do the job. The trouble is, as Hertz says, that all three ways of representing mechanics do a pretty good job, one better at this, one better at that. … Science is not [therefore] hypothetico-deductive. It does have hypotheses, it does make deductions, it does test conjectures, but none of these determine the movement of theory.[18]

We are gradually learning it seems that it is important to us that the world be open and capable of giving us fresh answers to new concerns we may have about it and about our own place, and that of other species, in it. The closure of the world to a knowledge couched in the terms of our own normativities of rationality locks us into an illusory position 'outside' and 'against' the world that is as unsustainable as it is destructive. It is in the end of value as well as inevitable that there should be different ways of seeing and understanding the world – the construction of different representations of reality provoke and stimulate different awarenesses and fresh insights that free us from old dogmas and present us always afresh with opportunities for re-imagining our own lives and those of others.

Manipulation as method?

---

[18] H p. 141-3

> Experimentation has a life of its own.[19]

Hacking uses the example of microscopy to demonstrate just how much doing and skill is involved in *seeing* and just how varied are the modes of seeing we have developed by technological means. Microscopy has developed sophisticated techniques to overcome artifacts of the optics and to transform and enhance the image produced to the end of effective seeing. The practical concern and involvement scientists have with the produced image and their treatment of it in the laboratory as wholly equivalent to a straightforward visible image, stands opposed to statements by philosophers of science, and even microscopy manuals, that what we see through the microscope cannot be understood literally as a visual image. Hacking first emphasizes the way we *learn* to see in unfamiliar modes or media. As with all perception – we see this explained well by a psychologist like J.J. Gibson[20] and by a philosopher like Merleau-Ponty[21] for example – the role of movement and a whole-body involvement is basic, and we convince ourselves of the veracity of what we see also by manipulating what it is we are looking at. This manipulation may be physical certainly, but it is also linked to the expectations we have of the specimen and the way it may behave which is built up on the basis of a large number of what we can think of as conceptual generalizations.

> We are convinced about the structures we seem to see because we can interfere with them in quite physical ways, say by microinjecting. We are convinced because instruments using entirely different physical principles lead us to observe pretty much the same structures in the same specimen. We are convinced by the clear understanding of most of the physics used to build the instruments that enable us to see, but this theoretical conviction plays a relatively small part. We are more convinced by the admirable intersections with biochemistry, which confirm that the structures that we discern with the microscope are individuated by distinct chemical properties too. We are convinced not by a high powered deductive theory about the cell – there is none – but because of a large number of interlocking low level generalizations that allow us to control and *create phenomena* in the microscope. In short, *we learn to move around in the microscopic world*.[22]

What Gibson and Merleau-Ponty confirm in their respective views on perception is that our sense of the reality and veracity of the world is given in the crossings of multiple and overlapping awarenesses at sensory and conceptual levels – but more important, that these awarenesses are gained as a product of our action and involvement and immersion in (our everyday exploration of) the properties and extensions of that world. Hacking finds some support in Dewey's instrumentalism: the things we make (including theories, public representations, equipment and language) are instruments we use to intervene in order to turn our experiences into thoughts and deeds that serve our purposes.[23] For Hacking

---

[19] H p. 150

[20] J.J. Gibson (1986), The Ecological Approach to Visual Perception, LEA Publishers, Hillsdale NJ.

[21] M. Merleau-Ponty (1983), The Structure of Behaviour, Duquesne University Press, Pittsburgh Penn.

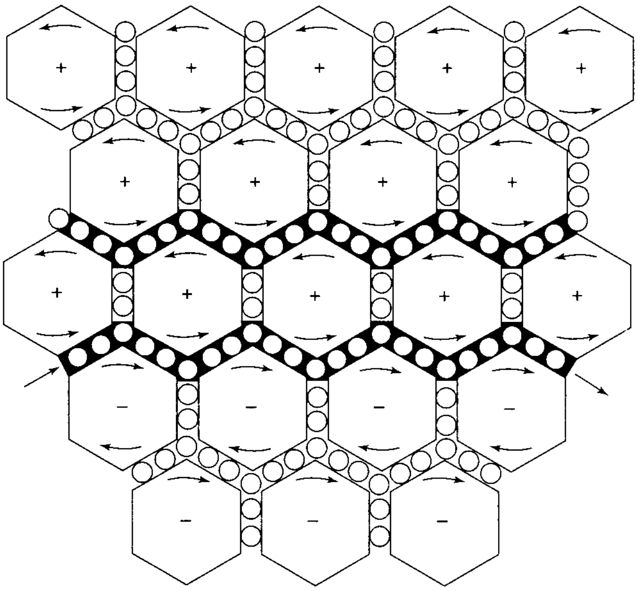
[22] H p. 209 (my emphasis)

[23] H p. 63

then, the real problem lies not primarily in a wrong conception of representation, it lies firstly in the bias and priority we give thinking above acting.

> [T]he jargon of philosophers … arise from contemplating the connection between theory and the world. All lead to an idealist cul-de-sac. None invites a healthy sense of reality. … I follow [Dewey] in rejecting the false dichotomy between acting and thinking from which such idealism arises. Perhaps all the philosophies of science that I have described are part of a larger spectator theory of knowledge. Yet I do not think that the idea of knowledge as representation of the world is in itself the source of that evil. The harm comes from a single-minded obsession with representation and thinking and theory, at the expense of intervention and action and experiment.[24]

We act on things, and on things we can manipulate. We may follow the history of electromagnetism to show us the role an active speculation and visualization – often addressed to rather concrete things – plays in the formulation of ideas about the world and the things that happen in it.[25] The forms this speculation takes, even when they involve numbers and quantities, tend to be qualitative and not quantitative – and tend to be organized around orders of pattern. Even quantitative values are imaged in forms that can be grasped visually. The field speculations of Faraday were eventually formalized and mathematized by Maxwell, and the mathematization came by way of the construction below.



Peter Galison speaks of the role of images in the invention of our worlds:

> We must have scientific images because only images can teach us. Only pictures can develop within us the intuition needed to proceed further towards abstraction. We are human, and as such, we depend on specificity and materiality to learn and understand. Pictures, sometimes alone, sometimes in sequences, are stepping stones along the path towards the real knowledge that intuition supports. First, Plato says, we grasp the triangle in the sand, then the triangle drawn more finely, then triangles in general, then the idea of triangles behind all particularities of individual triangles. But the virtue of pictorial representation goes beyond pedagogy and abstraction – it extends to discovery. For we can ask: What are humans good at?

[24] H p. 130-1

[25] See: Peter Pesic (2003), *Seeing Double*, MIT Press, Cambridge Mass. ch. 6

> We are good at recognizing and seizing upon visual patterns. We grasp family relationships among tactile-visual forms, we extend, modify, innovate on the basis of intuition *(Anschaulichkeit)*. Perhaps this is because the long process of evolution has left us with a pattern-recognition capability well matched to the world. Perhaps it is a psychological or socialized virtue inculcated by experience. But whatever its source, the power of pattern recognition is a crucial feature of scientific discovery; one we cannot and should not forgo. Finally, beyond pedagogy or even epistemology, images get at the peculiar – the unique – features of nature in a way that calculation or verbal description can never do. By mimicking nature, an image, even if not in *every* respect, captures a richness of relations in a way that a logical train of propositions never can. Pictures are not just scaffolding, they are the gleaming edifices of truth itself that we hope to reveal. So goes the brief for the scientific image: pictures are pedagogically, epistemologically, and metaphysically inalienable from the goal of science itself.

Galison goes on to play devil's advocate: "images deceive" he tells us. "Abstraction, rigorous abstraction, is exactly that which does not depend on pictures. … Rigorous, logical *non*-intuitive reasoning is the royal road to knowledge … we are capable of a cognitive austerity that refuses to stare at the seductive image and instead demands hard-edged, uncompromising understanding. … In the end, the truths of the world will be given to us by the relentless application of logic tied strategically to experiment; truth is something wider and deeper than the pictorial imagination can ever hope to encompass."[26]

Galison comes down, in fact, not on one side or the other. His line is to develop Hacking's argument about the layerings of our veridical perception – and of our in-the-world *involvement* with the object of our scientific or whatever attention. It cannot be simply that diagrams, images, models give us themselves as straightforward representatives of the objects and processes we seek to know: it is in the end a familiarity with an '*environment'* of knowledge – and here we are talking as if it were a 'landscape' we construct, inhabited by things, concepts, formalizations, as well as their logics and their manipulable relations with each other. And again, we convince ourselves about the veracity of the stuff we deal with by moving amongst it all and by using it *to do things*, to change things and to create new things. The landscape contains images, as representatives of various entities, but the landscape itself becomes spatializable, as a 'map' of the 'territory' of the problem. We are in there, part of the melee, part of a community of hybrid entities, and our diagrams are maps whose configurations we control as we establish *telos*, end, purpose – and ultimately *reason*.[27] We give up our belief in a singular logic – God's rationality that pretends to be universal as it denies its status as normativity. We seek instead the logics of the processes that confront us neither from above or below but from some middle point that situates our own positive perceptual and

---

[26] G p. 300

[27] The point is difficult but crucial. We construct a 'system of causation' of the problem or the 'matter of concern' (to use Latour's expression) whose logics are *of* that problem – constructed by the capacity of one of the internal constituents ('the observer') to select the order of the constituents to be considered. I discuss this in more detail in *Urban Life* (Techne Press, Amsterdam, 2007), ch. 3.

exploratory action. It is from this middle point that we engage, according to Galison, in an oscillation between visualization and calculation whose purpose is the manipulation of ideas and things in order to produce the effects which will convince us of the efficacy of our procedures.

And, more than ever today images proliferate out of the exploratory process itself:

> … almost at once, in every one of these new laboratories, the images themselves begin to dissolve, morphing into other forms. A flash of light and three cameras would capture a complex trail of bubbles in stereo relief. Then a scanner projected the pictures one by one onto a table, where she (almost inevitably she during the 1950s and 1960s) clicked a mouse-like device to enter space coordinates. Digitized, the information flowed into a computer which then crunched the data into idealized mathematical curves; from those curves the computer spat out punch cards with the particles' identities and properties. At first by hand and later by computer, the morass of numbers could finally be reassembled into new images: bar graphs or the so-called Dalitz plots where an entire picture would be reduced to a single black dot. The physicists could then ask: Did the dots cluster? Did the bar graph show one peak or perhaps two? An invisible physical process made bubbling tracks, tracks to numbers, numbers back to pictures. Those pictures in turn could themselves be analyzed back into numbers. … Bit by bit over the last few decades there has been a remarkable transformation in all these binaries. In each instance the image followers found themselves manipulating data banks, and the numerical-logicians found themselves gazing into the face of a picture. In the science of the very small, physicists have even brought cognitive science into their strategies for the visual display of digital data – the need to visualize crossed with the need for manipulable 'logic'-based data. … Such movements back and forth across the pictorial/analytic divide are, I believe, woven deep into [science], not so much in the epochal battles of the intuitionists and logicians (or of Heisenberg and Schrödinger), but instead in the quotidian details of practice…[28]

So, what is all this to-ing and fro-ing about? Getting a theory to mesh with possible configurations of nature was supposed to be just a matter of articulation and calculation. We would begin with speculations that we gradually cast into a form from which experimental tests could be deduced. What we find in fact is that this is not so. There are enormously complex and wide-ranging intermediary levels, well-known to practicing scientists (it occupies most of their hours on a day to day basis), while being for the most part erased from the theory. From the perspective of theory (or from that of the non-practicing 'scientist' who likes to instruct others about the 'correct' way of going about things), this level is lost to view. It is a level that addresses the cognitive dimension of what we do as scientists, and a level we could perhaps best call 'model-building'.

> The word 'model' has come to mean different things in the sciences. In the early days of molecular biology, models of molecules were like scale models of aircraft that children make as a hobby. That is, they were bits of wire, wood, plastic and glue. I have seen attics full of discarded molecular biology models, made with spring washers, magnets, lots of tin foil and such. Some nineteenth-century physicists made similar hold-in-your-hand models of the inner constitution of nature, models built with pulleys, springs, string and sealing wax. Most generally, however, a model

[28] G p. 319-21

> in physics is something you hold in your head rather than in your hands. Even so, there is an odd mix of the pictorial and the mathematical.[29]

Speculations and the theories they prefigure are in other words built, as part of an active scientific practice – and the building involves us in model-making. Then often, phenomena are created in apparatus, which will in some sense mimic or react to models. And all this creation and construction takes place in the *local*. Local events may transport of course, but this in no way given or guaranteed in the first place; the production of phenomena needs to be repeated and demonstrated before we will begin to take this transportation as something reliable, something we can (along with the apparatus that produces it) transport from place to place.

We see E.H. Hall in 1879, checking out a speculation by Maxwell, writing to his mentor:

> It seemed hardly safe, even then, to believe that a new phenomenon has been discovered, but now after nearly a fortnight has elapsed, and the experiment has been many times and under various circumstances successfully repeated … it is perhaps not too early to declare that the magnet does have an effect on the electric current or at least an effect on the circuit never before expressly observed or proved.[30]

Hacking's reaction to all this:

> [W]e tend to feel, the phenomena revealed in the laboratory are part of God's handiwork, waiting to be discovered.
>
> Such an attitude is natural from a theory dominated philosophy. We formulate theories about the world. We conjecture various laws of nature. Phenomena are regularities, consequences of these laws. Since our theories aim at what has always been true of the universe – God wrote the laws in His Book, before the beginning – it follows that the phenomena have always been there, waiting to be discovered.
>
> I suggest, in contrast, that the Hall effect does not exist outside of certain kinds of apparatus. Its modern equivalent has become technology, reliable and routinely produced. The effect, at least in a pure state, can only be embodied by such devices.[31]

Historical objects

We can begin to understand specific concerns in an open and complex world as demanding local explorations – in order to discover possibilities of passage that prove nothing beyond themselves, that authorize neither generalization or method. A notion of complexity sets out *problems* rather than solutions because we cannot know what 'sums of parts' mean when we cannot be sure that all the possible 'sums' of 'parts' are treatable under the same general model.

> [S]cientists ask the questions, and complexity arises when they have to accept that the categories of understanding that guided their explorations are in question, when the manner in which they pose their questions has itself become problematic. But

---

[29] H p. 216
[30] H p. 225
[31] H p. 225-6

> the question of complexity also leads to that singular category of objects that must be called historical, whether we are dealing with the living or with their societies. … [C]omplexity is not a theory, an exportable general model. The 'complex' lesson of dissipative structures is not the appearance of coherent collective behaviors but this … factor that, according to the circumstances, can be insignificant or 'change everything'.[32]

We encounter the problem of 'the critical' – a different critical to that of Kant, a critical that belongs to the material itself rather than to the realm of our categories. At the critical point of phase transition, a gas is no longer a gas, but neither is it strictly speaking a liquid: fluctuations of density that express the formation of droplets can take on macroscopic dimensions, reverberating their effects throughout the system. The scope of repercussions of the local event becomes global and the system as a whole reacts to what is happening in its smallest parts. Here is one of the places where we most obviously encounter the limitations of the general functions that populate our sciences. Here we find that average values are not valid a priori, but only within the limits *decided by the functioning of the system itself*. We have our laws by the provisional grace, in a manner of speaking, of the internal functioning of the particular systems that produce them. This internal functioning is a matter not of the laws but of the highly detailed coupling of minute processes which constitute it. We come to the point where we find real-world systems, which we understand under classical science as closing themselves around universal laws and upholding our macro-micro, global-local distinctions, in fact remaining open as a function of their own processes. We encounter points in that minute internal functioning where quite suddenly 'bifurcations' and 'points of criticality' may be attained. And that these bifurcations mark the instantiation of another order of organization rather than a breakdown of what is ordered.

But we find also a complication of matters with regard to the role of time in complex systems. Here we may be forced to consider a different attitude to the 'distribution of explanation' in science. Classical science has the tendency of concentrating the singularity of the object under consideration on a single mechanism. Stengers illustrates by looking at Darwin's 'natural selection', where "selection gives to the living its only conceivable meaning."[33] The question becomes one of how selection can evolve structures that are genetically constrained but not genetically determined, and here the role of time is crucial. Conrad Waddington saw that the living organism is not a determination of selection but rather a construction that integrates genetic constraints and interactions with the surroundings. Waddington introduced his idea of canalization, based on the Whiteheadian concept of concrescence.[34] He understood developmental processes to be morphological and diachronic in character, taking place in highly specific situated arrangements involving precise physical conditions. His view was of a 'growing together' over time of a large number of interlocking processes, and his abstraction was to imagine these processes occurring along canalized and stabilized pathways of

---

[32] S p. 13
[33] S p. 15
[34] Conrad Waddington (1957), *The Strategy of the Genes*, Allen & Unwin, London.

development, pathways he called ‘chreodes’. Following Whitehead’s system directly for a moment: we see that relations permeate through each thing, and that each thing is therefore only relatively independent. The important consequence is that no thing can be aggregated to others from the outside (as would happen with atomism). A new combination or thing can only grow by absorbing other things to itself, into the unity of its own individual experience, and this is in fact how we understand *internal* relations. Thus, when we look at a thing we always find a process, and never a fully autonomous or atomic entity, and all things in the world participate in the constitution of the new thing as an event. Concrescence is the name for this process in which a universe of many things grows into one more original individual unity, and so far as a thing cannot be separated from this activity, ‘concrescence’ and ‘thing’ are identical. As Whitehead puts it: “When we analyze the novel thing we find nothing but concrescence.”[35]

The point is that this emergence of new data out of old happens in a directed way: we could begin to talk of a ‘canalization of originality’ – which is of course the very productive process itself. For Whitehead, canalization both limited and magnified the creative process, allowing things begun to come to completion.[36] Canalization is the constraint that a ‘society’ of things imposes on the possibilities of future becomings of things; it binds originality within bounds so that the organism may itself be preserved as an ongoing process. Note that there is a certain ‘goal-directedness’ (telos) about the process which has the effect of preserving the character of the ‘life’ generated in what is in effect a continual eruption of newness. Note also that what we are looking at is the emergence of a new entity with its own time of becoming, with its own natural rhythms and pace.

> The fact that physics can now describe regimes of functioning that are both determined and open onto the external world, integrating in a singular global function the rules that govern the transformations in the system, the present circumstances, and the past history of the system, obviously proves nothing outside of physics. Nevertheless, it is possible that the awareness of a certain conceptual vacuum will actualize this and cease being filled with the paradoxical association of disparate concepts. It is important here to remember that we do not yet have at our disposal any theory of organization. And if one considers, in the work of Jacques Monod, for instance, the crucial weight of arguments and metaphors drawn from, on the one hand, both cybernetics and information theory, and on the other hand, classical physics, one cannot underestimate the importance of the recognition by physics that the description of an ‘organized situation’ is quite an open problem.[37]

We are left in a world without a formula – where we can guarantee only that new things and the unexpected may arise at any moment, and where we understand that history belongs to the things themselves and to their own processes of becoming, rather than to some universal overview or some decree of an overarching authority. We are left in other words in a situation of

[35] A.N. Whitehead (1929), *Process and Reality*, Cambridge University Press, Cambridge, p. 243
[36] ibid, pp. 127, 151.
[37] S p. 73. With regard to the ‘determined and open’ in science, see further: Stuart Kauffman (2000), *Investigations*, Oxford University Press, Oxford.

uncertainty and risk, but also in a world whose processes we may track and about which we may ask questions. The questioning of the world, itself becomes a risk; how do we know that the question we ask is the *right* question? How do we know we ascribe the right 'sum' to the right 'parts'? We inscribe some of the patterns we find into our technologies of seeing and understanding, and we build in this way purpose and direction into our frameworks of knowledge, which nonetheless remain provisional and limited by the scope and problematic of the question addressed. The representations of Hacking may become also representatives: maps and also models and apparatus that don't so much judge the phenomena as *produce* them in appropriate or fortuitous circumstances.

Science becomes a radically inventive-interventive process that itself proceeds historically, from event to event, between rationality and reality (between thought and the world), and with high levels of accident, incident, and contingency along the way. We make voyages of discovery into uncharted territories – well, let's say into territories that are not entirely charted. We may have conducted forays into these foothills before, and have some idea of what we might encounter, but yet have no idea what unexpected mishaps and fortuitous turns may lie in wait for us on this particular journey. We take with us maps of our previous ventures, and pore over them around the camp-fire, speculating on where exactly we are in relation to previous voyages and what we may expect to encounter the next day. We leave nothing to chance, leave no option we can imagine unexamined, and yet know we may at any time encounter what we least expected. And, in a sense the least expected is what we seek: if we could guarantee the outcome of our journey, we would not have the motive to undertake it in the first place. We voyage to discover in a universe whose passage from conditions to consequences is and must be discontinuous and risky.

> [T]he objects which science constructs, those which figure in developed physical knowledge, are always clusters of relations. And it is not because structure, by its essence, resists expression that physics only barely succeeds in formulating the laws of certain structures in mathematical language; it is because the existential solidarity of its moments renders the experimental approach difficult, prevents acting separately on one of them, and demands that a function which is appropriate to all of them be found initially. One cannot even say that structure is the *ratio essendi* of the law which would be its *ratio cognoscendi*, since the existence of such a structure in the world is only the intersection of a multitude of relations – which, it is true, refer to other structural conditions. Structure and law are therefore two dialectical moments and not two powers of being. What is demanded by physics is in no case the affirmation of a 'physis' – either as the assemblage of isolable causal actions or as the place of structures – or the power of creating individuals in-themselves. Form is not an element of the world but a limit toward which physical knowledge tends, and which it itself defines.[38]

To say that structures are in nature, and that mind can be constituted from them, as Gestalt does, is therefore way too simple and excises the risk and the radical contingency from our project of the construction of knowledge. The

---

[38] M. Merleau-Ponty (1983), *The Structure of Behavior*, Duquesne University Press, Pittsburgh Penn. p. 134

territory, Gregory Bateson tells us, is not the map; the thing is not the word. What we deal with is a choppy sea of 'difference' – 'information' for a cybernetician like Bateson – which is quite real and yet quite other than the simple matter of the atomists, and the precondition, before matter, not just for perception but also for the language in which we describe it. We make inroads into the territory by risking the journey. The question of whether we must know the world in order to intervene in it or intervene in the world in order to know it is one we can begin to understand and accept – as we accept the fundamental provisionality of the charts we make of the territory, and the risk entailed in any subsequent intervention. The question of method, and of the unity of knowledge are capable of being misappropriated, perhaps to hold science in a vise which forbids talk of speculation while pretending its results are somehow beyond speculation. We need to get used to the way the world refuses to converge definitively around the principles we concoct for it – as if it would have nothing to say about the matter itself. And then we may begin to revel in the possibilities for invention and the opportunities of circumstance this awareness opens up. We join with other explorers in opening ourselves to the benefits and risks of contingency. We learn that contingency is also generous and we begin once again to come away with more from our ventures towards knowledge than we put in at the beginning.

Rounding off

I aim here to subtend a tedious and I believe superfluous discussion that goes on in some circles (not many – most scientists are too busy exploring, inventing and intervening to bother themselves much with all this), about method, truth and validity in research. Research pathways may become 'normal' and institutionalized and live on doing something they have done for years or decades (and often usefully) but without questioning or exploring any longer their basic assumptions. Within this pathway the things the particular 'method' and 'truth' does well are pursued, while those it has no grip on simply drop out of sight – and may even become dismissed as non-researchable by those committed to the negativity and tedium of gate-keeping around their particular 'normality'. Creative working people on the whole welcome the jolt of the unfamiliar; they embrace the shock of the new when it looks as if it creates an opening to new and stimulating lines of research. The best example spanning the major shifts in thinking about the physical universe over the last 3 or 4 centuries is still that of gravitation and its anomalous 'action at a distance' – which shifted from being something of an embarrassment in the Newtonian clockwork universe, to being simply invisible as an anomaly as far as most scientific practice was concerned. We all know that it was here – in the zone the working practices of the clockwork universe eventually forgot about – that the next great advances in natural science took place; advances which the scientific community have accepted enthusiastically as opening challenging new lines of research. Not everything new or different is worth the trouble of course; so much goes without saying, and everything new or different deserves to be subjected to the closest examination and argument and constructive and informed dispute. But to reject the new or the different in principle, and in the name of a 'culture' that is elevated to some sort of untouchable and unarguable status (to the status of dogma) is, I would argue, simply counter to the spirit of scientific endeavor and a matter for theology.

For us, the city is a dynamic and historical object with the power to move itself. It is also intimately ours, the field of presence of us and our objects, and of our encounter with others. It may, in its dynamism, be constitutive of the kinds of beings we are. We are minutely bound up with its movements and evolutions which will serve to situate us in the places from which we see and act:

> Michel Serres has often invoked the respect that peasants and seafarers have for the world in which they live. They know that one has no control over time and that one cannot rush the growth of the living, the process of autonomous transformation that the Greeks called *physis*. In this sense our science is at last on the way to becoming a physical science since it has to finally accept the autonomy of things, *and not only of living things*. Human activity contributes to the production of a new state of nature. As with the development of plants, the development of this new nature, peopled by machines and technology, the development of social and cultural practices, and the growth of cities are continuous and autonomous processes in which one can certainly intervene to modify or organize them, but whose intrinsic time must be taken into account, under threat of failure. The problem posed by the interaction of human populations and machine populations has nothing in common with the relatively simple and controllable problem of the construction of this or that machine. The technological world that classical science contributed to creating needs quite different concepts from those of classical science in order to be understood.[39]

[39] S p. 57