Statistical physics of disordered systems: spin glasses, neural networks and other applications
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Frontiers and complexity

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I. Introduction

In view of the circumstances, the best is to start with an extract from Darwin's autobiography:

He [Charles Lyell, 1797-1875] reminded me that I had many years before said to him, when discussing the opposition of the old school of geologists to his new views, 'What a good thing it would be, if every scientific man was to die when 60 years old, as afterwards he would be sure to oppose all new doctrines'. *But he hoped that now he might be allowed to live.* (Charles Darwin (1809-1882), Autobiography. Recollections of the Development of my mind and character, 1876)

At the time of their first discussions, Darwin was in his thirties and Lyell in his forties, whereas the subsequent comment took place twenty years later, when Darwin was in his fifties and Lyell had crossed the frontier of 60.

This talk is going to be a roundabout promenade, in a spiralling way. In order to prevent you from getting irretrievably lost during my digressions (and in exchange for your indulgence), let me give you already a hint at the conclusions. My bottomlines will be two claims:

i) ethical questioning is a creative activity,

ii) ethics may be seen as an overarching level of complexity studies.

In other terms, no mature science of complexity could omit ethical considerations: ethics is on the horizon of complexity, and it is an adjuvant to inter-disciplinary cooperation. Several reasons concur to suggest that ethics is a proper concern for teaching and research institutions.

Clearly, these are not yet generally accepted views. So these statements are non trivial. But encouraging signs are detectable in many quarters around the world.

Returning to it, Darwin's quotation raises the problem of frontiers between age classes, and of fair-play between generations. Such problems exist in all sectors of society, but the spectrum of ages turns out to be specially wide open in the science profession (with students at one end, and academicians at the other).

Some genuine background for this talk has been provided by the experience of two pathways:

i) one is a personal trajectory, from youth to seniority, through age categories;

ii) the other is a thematic journey, going from matter to mind (as suggested by the title of this day) or from physics to metaphysics, i.e. a trajectory through the field of disciplines, going from the study of objects which are things, to the study of objects which are also subjects.

From these two experiences, one may draw reflections on the issue of frontiers, and of their crossing. Which borders should be respected ? Which boundaries are to be transgressed ? (Sometimes, we endeavour to establish norms, defences, barriers; sometimes, we take pride in breakthroughs, overpassing borders, and the crumbling of Berlin walls.)

II. Limits of science, and frontiers between disciplines

Are there legitimate boundaries of science ? Between science and eternal mysteries, or between science and other forms of knowledge (other modes of thought).

Is the value of knowledge absolute ? (Is it always better to know than to ignore ? and is it correct to say that humanity has acquired new knowledge, when this knowledge is not shared ?)

Is freedom of research a supreme right ?

Is the fastest accumulation of knowledge a sound guiding principle ? For instance, in discussions over regulation of intellectual property rights (patents, copyright, etc).

I am not going to deal with these important questions, but observation shows that beyond past (or recurrent) pathological attitudes and practices, there is a wide propensity among our scientific community to slip on these issues. Even among the best of us ...

Some of the hot issues are:

- human and animal experimentation,
- status of the embryo, beginning and end of life (the notions of dignity, and respect, are not scientific

statements),

- 'nothing buttery' (cf. Hubert Markl's speech, 22 June 2001, as President of the Max Planck Society: *Liberty, responsibility, human dignity: why there is more to life science than just biology,* available on www.mpg.de): the mind is 'nothing but' the activity of a bunch of neurons, life is 'nothing but' the motion of molecules; the book-title *L'homme neuronal* is an epitome of this reductionist bent;
- impunity culture (objective and value-free, science is by definition pure and innocent; scientists bear no responsibility for bad consequences).

In brief, we scientists are a population at risk (une population à risques), meaning that there are limits which we tend not to perceive; our formation makes us predisposed to selective forms of blindness (more on that in Section 4).

Deep similarities exist between inter-disciplinary conflicts and inter-ethnic conflicts.

The basic and widespread source of prejudices is a worst-case classification of the other group (think of the image of: lawyers, economists, sociologists, biologists, chemists, etc, as seen from within the physics community) -- with often a stubborn attachment to objective facts, endlessly repeated as evidence --, whereas one's own community is evaluated quite differently: according to its saints, its heroes, its mythical and perennial ideals. The bias in these judgment criteria is so ingrained as to remain unnoticed. During the last four decades, the theme of the conflict between two cultures (sciences and humanities; à la C.P. Snow) has been steadily growing, and expanding into reports about multiple occurrences of 'science wars'.

According to Samuel Johnson, *nationalism is the last refuge of the scoundrel.* Disciplinarism fares scarcely better.

III. Ensembles of objects and subjects

The statistical physics of phase transitions and disordered systems raised hopes (still alive) of forging new conceptual and analytical tools to describe complex systems. Such as:

- transitions sharp or gradual (discontinuous or continuous),
- liquid-gas transitions terminating at a critical point,
- non-holonomy effects (topological defects whose character, and interaction properties, appear transmuted after circumnavigation around another defect),
- non-transitivity effects in taxonomy (such as sub-species group A inter-breeding with B, B with C, but not C with A), remindful of frustration (in material systems),
- ultrametricity property of spin-glass energy landscapes (hierarchical distribution of valleys within valleys), bearing similarity with the evolution tree (hierarchical taxonomy of species), as described one century and a half earlier by Darwin: *Life is an irregularly branched tree,*
- most probable value of an ensemble, differing from average value, differing from worst-case analysis.

The elaboration of these concepts, during the seventies and eighties, were enlarging our views about categorisation (making our analyses more subtle and diversified). And these conceptual developments seemed to be converging, with other streams in natural and social sciences, toward a global synthesis: the project of a science of complexity became explicitly advocated by the Santa Fe Institute during the nineties.

About the status of exceptions.

Exceptions are commonly discarded as statistically non significant, or gently dismissed as 'exceptions which confirm the rule'. This logic is one basic plague in the objective analysis of subjective beings. Modern racism was nurtured by this 'methodology'.

In his *Essai sur l'inégalité des races humaines,* Gobineau makes clear his point: *Encore une fois, et cent fois, ce n'est pas sur le terrain étroit des individualités que je me place. Il me paraît trop indigne de la science de s'arrêter à de si futiles arguments ... Laissons donc ces puérilités, et comparons, non pas les hommes, mais les groupes [...]. Ce travail difficile et délicat ne pourra s'accomplir tant qu'on n'aura pas balancé de la manière la plus exacte, et, en quelque sorte, par des procédés mathématiques, la situation relative des races.* (quoted in Stephen J. Gould, La mal-mesure de l'Homme, Odile Jacob, 1997)

No scientist can ignore the impact of odd individuals, such as Marie Curie (Polish woman in France) or Abdus Salam (Pakistani moslem in Europe), and their long-term influence as role models for subsequent generations. This pioneer effect is not only true for eminent scientists in fundamental research, but also for entrepreneurial 'business angels' in the development of new technologies. Thus affirmative actions have a potential to promote exceptional profiles and, in the event, the example provided by these individuals may infirm and modify the rule, instead of confirming it. Indeed, such was one of the motivations behind the creation of the Rammal Medal (1993).

Another common temptation, recurrent in any process of objectivation, is quantitative evaluation, taking generally the form of reduction to a one-dimensional scale, and associated with an optimization principle. Four instances may be selected as illustrations: utility (a central concept for the doctrine of utilitarianism), cost-benefit analysis (used in risk assessment), intelligence (measured by brain size, or by I.Q. tests),

professional quality (measured by citation statistics, impact factors, etc).

There is an element of irony in the last case, because this quantitative evaluation method is now back-firing on the scientific professions. In a recent issue of Nature (14 February 2002), prediction was made that scientists would soon be ranked like tennis-players, according to a world scale based on 'objective' criteria. Like earthquakes on the Richter scale.

It happens that nature lacks wit: this is the ground that physics exploits.

Should physicists advance as far as they can go, using their bag of tools ? Is it heroic ? At which conditions, is it innocent ? These questions became an increasing concern for me, around 6-8 years ago.

In retrospect, this concern appears to have been enhanced by a conjunction of different factors (personal, local, national, european, global):

i) it was clear that my younger collaborators, now on the forefront of the statistical physics of disordered systems, were likely to do much better than I could, in these domains;

ii) my various efforts and initiatives (within education and research institutions, such as: ENS, Académie des sciences, CNRS, Société française de physique) were meeting pervasive obstacles to innovation (or even to simple adaptation), which seemed revealing of a common background: an absence of fair-play;

iii) corruption had always been endemic in France; however the recent wave was reaching new sectors and new levels, and spreading fast, not only in politics and business, but also among scientists and state-servants; suffice it to mention two major affairs (contaminated blood, association pour la recherche sur le cancer) and one Ubuesque minister of education and science;

iv) the failure of Europe to think and act properly during the Yugoslavian tragedy was an ominous symptom; in Srebrenica (1995) occurred the worst massacre on our Continent since WW2;

v) in this context, the emergence of collective ethical reflection in science, federating earlier moves from the inside and from the outside of the scientific community, appeared as providential: a promise of response to long-standing questions, and a promise of cure for pressing curses.

Indeed, ethics is the admission of, and arbitration between, different logics, values, interests, allegiances.

IV. Our scientific community as a population at risk

Modern science, since its dawn in western Europe during the 17th century, exhibits an unprecedented and spectacular dynamism. Like capitalism, it may be properly described as a process of destructive creation (Schumpeter, Bachelard).

The emphasis has been on mobilisation. Impetus, momentum; premium to priority; the farther, the faster. Scientists are trained to be race leaders, research is a rush. (In French, the pictorial word 's'arracher' is used for bright students and scientists). Excellence, excitement: the prefix EX is the clue, denoting extraction, exit from rest.

Paradoxically science, which was an anti-fatalism (the fatality of inertia, as absence of motion), has given rise to a new fatalism (the fatality of inertia, as rigid, inflexible motion). *For progress there is no cure* (on n'arrête pas le progrès).

This neo-fatalism has been analyzed by the historian Marc Bloch, with astonishing lucidity (under most dramatic circumstances: during the summer 1940, following the débâcle):

Nous savions tout cela. Et pourtant, paresseusement, lâchement, nous avons laissé faire. [...]

Adeptes des sciences de l'homme ou savants de laboratoire, peut-être fûmes-nous aussi détournés de l'action individuelle par une sorte de fatalisme, inhérent à la pratique de nos disciplines.

Elles nous ont habitués à considérer sur toutes choses, dans la société comme dans la nature, le jeu des forces massives. Devant ces lames de fond, d'une irrésistibilité presque cosmique, que pouvaient les pauvres gestes d'un naufragé ? C'était mal interpréter l'histoire ...

The notions of free will, and personal responsibility, like human dignity, are alien to science. They are not scientific truths, they are beliefs. Rational beliefs. Their rationality comes from lessons of history: the observation of the unacceptable consequences of the neglect or rejection of these notions and values.

About experimentation in science.

The status of experimentation in modern science (natural and social sciences) raises several questions. A large set of regulations have been edicted, concerning human and animal experimentation in biomedical research. My focus here will be on the issue of the right to error in experimentation. According to Karl Popper, the crucial criterion for scientificity is falsifiability. On this basis, marxism and psychoanalysis were deemed unscientific, because non falsifiable. However nowadays, since the collapse of the Soviet Union, Marx's main prediction (that collective property of production means induces faster economic development) is generally considered as refuted. The experiment has been done, and the hypothesis has been disproved. But then it follows that marxism did prove refutable, and thus Popper's objection against its scientificity falls. Accordingly, Marx should be rehabilitated as a standard practician of hypothetico-deductive science. But was the experiment legitimate ? Was it worth acquiring this knowledge, at the

expense of so many victims ?

Let us now examine a quite different kind of scientific and technical experimentation. Our generation is that of the conquest of space, and four decades have been sufficient time for an irreversible pollution of the outer space of our planet. The geo-stationary orbits, which are especially sought-after for practical purposes, are already filled with space debris, which will stay on for millions of years -- a garbage which cannot possibly be cleansed.

Nowadays, it is common among scientists and engineers to express fears about risks of abuse of the precautionary principle. But honestly, during the last four centuries (the modern era), what danger has been prevalent: excess or lack of precaution ?

About autonomy and impunity culture.

The birth of modern science in the 17th century was accompanied with a (legitimate) concern for independence from religion and politics. This concern is explicit in the motto of the Royal Society of London (*Nullius addictus jurare in verba magistri,* used to swear in the words of no master; i.e. don't believe in tradition and authority, believe only in your observations and experiments) and in the statutes written by Robert Hooke (1663): *The business and design of the Royal Society is to improve the knowledge of natural things, and all useful arts, manufactures, mechanick practices, engynes, and inventions by experiments (not meddling with divinity, metaphysics, moralls, politicks, grammar, rhetorick, or logick).*

Quite normally, this aspiration to independence led to a claim for autonomy. The creation of science academies, during the modern era, has been propped up by this ambition. However, autonomy has two faces. On one side, it aims at protection of independence; but on the other, it brings the risk of nurturing an impunity culture (rejection of any control, irresponsibility). Examples abound to show that, all too often, the scientific community has been leaning on the latter side. Indeed, the emergence of the ethical movement in science may be interpreted as an awareness that this attitude is no longer acceptable.

A professional sector which is unfair in its external dealings with the rest of society, cannot be fair internally.

V. Attempt toward wisdom, and message of hope

Fair-play in science: between disciplines, regions, cultures, genders and generations.

One major injunction deriving from fair-play between generations is that scientific research should remain playful. Neither excess pressure, nor extra loads should be put on students and science-beginners. (As a side-remark about this play character, note the links between laughter and transgression of limits, and between humour and research.)

There are several nice features about fair-play:

i) virtuous cooperative effects between its various dimensions; for instance, fair-play between genders facilitates fair-play between generations and fair-play toward new disciplines; actually, it is not uncommon in science that enlarging a problem helps to find better solutions;

ii) efficient strategy to escape from blocked situations (fair-play behaviour tends to allow for better performance than a 'greedy' short-sighted algorithm), and from the traps of conformity;

iii) fair-play is often contagious (lack of fair-play, also).

Ethics inspires trust, and enhances alertness, comforting a capacity of resistance to the fatalism of inertia (whether inertia of immobility, or inertia of unadaptive routine).

*Every true scientist should undoubtedly muster sufficient courage and integrity to resist the temptation and the habit of conformity. (*Sakharov)

[Epilogue:

this was the end of my argumentation in favour of the two theses presented in the Introduction.

Before entertaining questions, I wish to express deep-felt gratitude to the organizers of this 'celebration' (and also to the speakers, and the participants). Your initiative took me by surprise, for two reasons. First, I belong to a numerous generation, and there can't possibly be events dedicated in honor of each of us; so such celebration has become quite a distinction. Second, of course I was expecting some form of recognition, but I had come to think that it would be posthumous. So now, as I am enjoying this festivity, and still alive ..., I feel also requested to address the Lyell-Darwin question.

As a scientist, "may I be allowed to live" after crossing the barrier of 60 ?

To a large extent, I have been fortunate with the worldwide advent of the ethical movement in science, which may have saved me from some standard old-age pitfalls, or from resignation to fatality. An opportunity was offered to remain faithful to my youth aspirations, and to keep on the breach of a frontier, engaged in another challenging (open, difficult) adventure.]