Dottorato in Filosofia e Teoria delle Scienze Umane

CICLO XXIII

The concept of interaction: crossovers among biology, logic and philosophy

Giulia Frezza

Tesi di dottorato in cotutela
Università degli Studi Roma Tre

Thèse de doctorat en cotutelle
Université Denis-Diderot, Paris VII

A. A.: 2010/2011

Tutor della tesi in Italia:
Prof. Vito Michele Abrusci, dip. Filosofia, Università degli Studi di Roma TRE
Co-directeurs de thèse en France:
Prof. Claude Debru, dépt. Philosophie, ENS, Paris, Université Denis-Diderot, Paris VII
Prof. Giuseppe Longo, CREA, dépt. Informatique, ENS, Paris
Coordinatore: Prof. Paolo D'Angelo

Index

Introduction

The interaction: a concept, two (hi)stories

Mais, pris comme le patient lui-même dans l'alternative réel-imaginaire, comment échapperait-il au double risque, soit de voir l'intérêt pour l'analyse s'effondrer si d'emblée l'analysé apprend que tout le matériel produit n'est qu'imaginations (*Einbildungen*), soit de se voir reprocher plus tard de l'avoir encouragé à prendre ses fantasme pour des réalités?
J.-B. Pontalis, J. Laplanche

Therefore, things must be learned only to be unlearned again, or more likely, to be corrected.
R. Feynman

1.

We can all reach an ordinary intuition of what the concept of interaction means, for instance by looking at the juxtaposition of its components (inter and action). Moreover, we seem to know a lot about this word, we hear it very frequently in various situations (such as everyday speech, but also scientific and academic ones) as well as in the media[1]. Thus we could say we are used to it, nonetheless if we start asking for it precise meaning and the reason of its diffusion we may have some difficulties in finding a ready answer[2]. And looking at the history of its components

[1] Examples of quotes from *Century Dictionary*: (1) "Well - the interaction is a voluntary act from both consenting parts so, I don't think its a distraction". —*The Wall Street Journal*, "Web Chat With Guillermo del Toro"; (2) "The traditional high-priority subjects of our interaction is anti-terrorist preparation of the U.S. and Russia". —*CNN* Transcript Sep. 16, 2005; (3) "This binding, this highly specific protein-protein interaction, is what initiates the activity of our adaptive immune system". —*California Literary Review*.

[2] *American Heritage Dictionary*: 1. noun: The act or process of interacting. 2.noun: The

("inter" and "action") we cannot probably go very further in the quest. The term "interaction" does not even seem to have developed in the same way as other notions which are semantically related or strictly involved in its conceptual family such as "to interact", "to interplay", "to intervene" which for instance are much less widespread...[3] Which is then the peculiarity of this concept?

As you may understand from the arguments brought on till now, despite its interest I am not specifically concerned here with the traditional history of the term from a linguistic-historical standpoint[4]. In spite of that, I will stress one of the possible epistemological (hi)stories of the concept of interaction, considering its increasing explicative power and diffusion in recent history, and especially in the life sciences.

> [...] Les interactions sont des actions réciproques modifiant le comportement ou la nature des éléments, corps, objets, phénomènes en présence ou en influence. Morin (1977), p. 51.

When I started to consider more attentively this term which I saw employed in so many different areas and disciplines, I discovered some peculiarities and I became more and more curious of finding out something more. After a brief analysis of the use and diffusion of the concept of interaction in different scientific disciplines I have noticed an intense and extensive growth especially within the last twenty years

---

state of undergoing interaction. 3.noun: Physics, Any of four fundamental ways in which elementary particles and bodies can influence each other, classified as strong, weak, electromagnetic, and gravitational. *Century Dictionary*: (1) Mutual or reciprocal action; action or influence of things upon each other. The interaction of the atoms throughout infinite time rendered all manner of combinations possible. Cit. By Tyndall: "There can be no morality when there is not interaction between the moral subject and the moral object". H. N. Day, Princeton Rev., Sept. (1879), p. 311. *GNU Webster's* 1913: 1.noun Intermediate action. 2. Noun: Mutual or reciprocal action or influence. 3. noun: the effect, such as exertion of a force, that one object exerts on another, especially the capture or emission of a particle. 4. noun: Communication between people, or the actions of people that affect others. *WordNet*: 1.a mutual or reciprocal action; interacting 2. (physics) the transfer of energy between elementary particles or between an elementary particle and a field or between fields; mediated by gauge bosons.

[3] Used in the came context: relationship · communication · behavior · contact · analysis · integration · cooperation · stimulation · involvement · contribution · input · evolution · exchange · manipulation · distribution · transition · modification · research · environment

[4] Term "interaction"(1832): from inter- + action; "to interact" (1839), probably a back formation from interaction. Related: Interacted; interacting. "to interplay" (1862), from inter- + play. "Reciprocal play," thus "free interaction"; action mid-14c., from O.Fr. action (12c.), from L. *actionem* (nom. *actio*), from pp. stem of *agere* "to do" (see act). Meaning "fighting" is from c.1600. As a film director's command, it is attested from 1923. Meaning "excitement" is recorded from 1968. Phrase "actions speak louder than words" is attested from 1845. http://www.lexilogos.com/etymologie.html

(1980-2010, see table 1). More properly I have delineated two different tendencies: on one side a horizontal “ext-ensivity” (diffusion) of the concept and on the other also a vertical “int-ensivity” (frequency) when considering its increasing employment throughout the years.

The analysis of the first diffusion of the term brought us back to the 18th century (see table 1), but only in the most recent years we notice an increase in its use, even suggesting the possibility of an *abuse* of it. The point of view of this research would therefore be critical: trying to put together the puzzle which emerges from the conceptual analysis and from an epistemological-historical recognition of the notion of interaction. This standpoint would emphasize the importance of the influence of language and *Zeitgeist* on culture, scientific researches and scientific language according to a critical-epistemological approach which has recently been referred to as the “epistemological culture” under/behind/over/inside science developments (Fox-Keller, 2002). The traces of cultural thought might normally rest unperceived and yet they are implicitly “active”, penetrating and working on scientific buildings.

Hence I will take this point of view for clarifying the influence of the concept of interaction in scientific matters, from its first developments in physics and psychology to the most recent applications particularly in biology and the life sciences. Doing this, I will put in evidence a *double lineage* of the concept of interaction: a linear-deterministic origin and a multi-factorial non-deterministic one. Following the interplay of these two branches we will better be able to understand some fundamental differences in its meaning, its employment and their consequences in scientific analysis.

2.

Let us examine some data from *Gallica, Bibliothèque numérique* which is the on-line catalog of the *Bibliotheque Nationale de France* archive (http://gallica.bnf.fr):

- there is only one occurrence of the term “interaction” in both the 16th and the 17th century

- there are 35 in the 18^{th}
- there are 140 in the 19^{th}
- there are 594 in the 20^{th} and
- there are 1653 occurrences in the 21^{st} .

Table 1.

In the 21^{st} century, as we see, we observe an exceptional growth; we should also remember that we are just in the beginning of the century. We need to remark that part of this growth is surely due to text availability; nonetheless the story seems to be worth a look. We also notice that among the principal occurrences there are:

- 56 references in the sciences (general)
- 20 in psychology
- 20 in philosophy

Let us add that a milestone of 19^{th} century biology such as Darwin's *Origin of species* does not have any occurrence of the term interaction. Consider that there are lots of references to related notions, such as the relation with the environment, the impact of one species towards another; for instance, there are six occurrences of the verb "to intervene" which is in fact quite similar in meaning to "to interact". We may start asking ourselves the reason for this, and a first answer is surely the more "recent" history of the term interaction, as we said, and its great diffusion nowadays that make us naïvely wonder why it was not as used previously as it is today.

If we now look at the *British Library* catalog we can proceed further in our quest for occurrences of the term of interaction. The *simple word* "interaction" occurs 10.323 times in the catalog. If we instead make a query for the *subject* of the books associated with the term "interaction" we find that it occurs:

- 573 times in Psychology
- 404 times in Communication
- 213 times in Chemistry
- 201 times in Physics
- 162 times in Biology
- 133 times in Media
- 130 times in Genetics (of which 113 in common with Biology)
- 121 times in Economics
- 117 times in Linguistics
- 108 times in Philosophy
- 82 times in Computer Sciences
- 73 times in Social Sciences
- 66 times in Politics
- 32 times in Cultural Studies
- 0 times in Anthropology
- 0 times in Literature

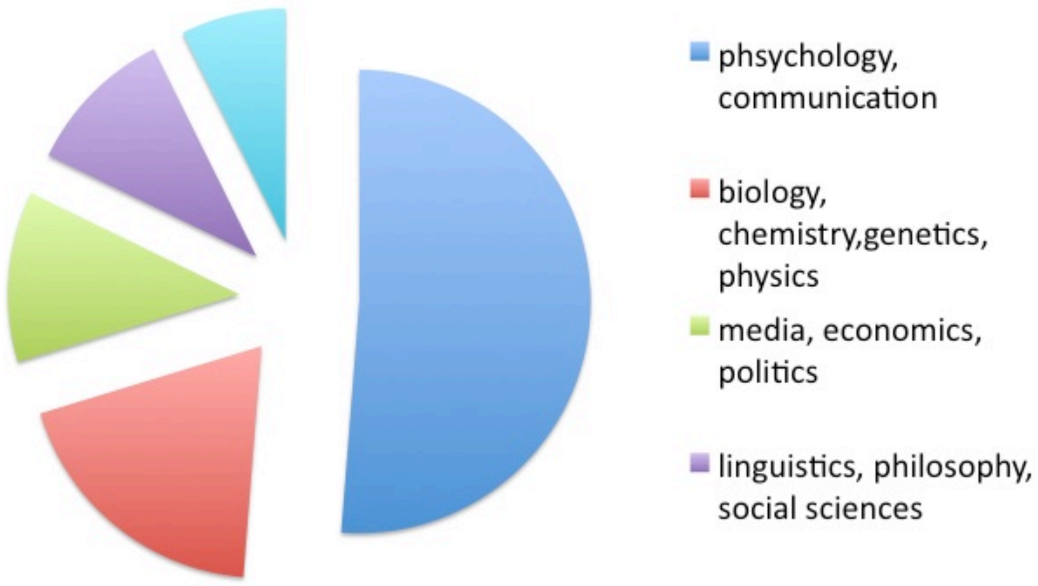

Table 2. Diffusion of the term “interaction” within different disciplines.

We are now able to set another type of screening by selecting four main epochs: years 2000^{s}-2010^{s}, years 1990^{s}, years 1980^{s} and years 1970^{s}. If we look at our previous data we get the picture above:

- 573 times in Psychology: 188 in the 2000^{s}, 186 in the ‘90^{s}, 127 in the ‘80^{s}, 62 in the ‘70^{s} and 3 in the ‘60^{s}
- 404 times in Communication: 160 in the 2000^{s}, 135 in the ‘90^{s}, 75 in the ‘80^{s}, 23 in the ‘70^{s}
- 213 times in Chemistry: 40 in the 2000^{s}, 80 in the ‘90^{s}, 84 in the ‘80^{s}, 6 in the ‘70^{s}
- 201 times in Physics: 31 in the 2000^{s}, 83 in the ‘90^{s}, 75 in the ‘80^{s}, 7 in the ‘70^{s} and 5 in the ‘60^{s}
- 162 times in Biology: 53 in the 2000^{s}, 68 in the ‘90^{s}, 38 in the ‘80^{s}, 4 in the ‘70^{s}
- 133 times in Media: 80 in the 2000^{s}, 27 in the ‘90^{s}, 22 in the ‘80^{s}, 4 in the

‘70s

- 130 times in Genetics (of which 113 in common with Biology): 49 in the 2000s, 56 in the ‘90s, 22 in the ‘80s, 3 in the ‘70s
- 121 times in Economics: 46 in the 2000s, 43 in the ‘90s, 22 in the ‘80s, 0 in the ‘70s
- 117 times in Linguistics: 46 in the 2000s, 47 in the ‘90s, 21 in the ‘80s, 3 in the ‘70s
- 108 times in Philosophy: 55 in the 2000s, 34 in the ‘90s, 15 in the ‘80s, 0 in the ‘70s
- 82 times in Computer Sciences: 40 in the 2000s, 26 in the ‘90s, 16 in the ‘80s, 0 in the ‘70s
- 73 times in Social Sciences: 33 in the 2000s, 17 in the ‘90s, 15 in the ‘80s, 0 in the ‘70s
- 66 times in Politics: 41 in the 2000s, 16 in the ‘90s, 6 in the ‘80s, 2 in the ‘70s and 1 in the ‘60s
- 32 times in Cultural Studies: 14 in the 2000s, 13 in the ‘90s, 21 in the ‘80s, 0 in the ‘70s
- 0 times in Anthropology
- 0 times in Literature

Table 3. Diffusion through the four main epochs.

We can add another element before trying to put these simple data together. Here we have, in table 3, the diffusion of the term interaction throughout years. We may comment that these data confirm our expectation and particularly that there is a continuous increase with a pick in the last twenty years.

2009	364	1999	365	1989	267	1979	157	1969	63
2008	412	1998	366	1988	220	1978	166	1968	45
2007	**464**	1997	330	1987	230	1977	195	1967	57
2006	389	1996	347	1986	207	1976	142	1966	27
2005	390	1995	302	1985	199	1975	160	1965	41
2004	384	1994	302	1984	196	1974	154	1964	31
2003	390	1993	271	1983	196	1973	105	1963	22
2002	373	1992	304	1982	179	1972	106	1962	11
2001	385	1991	283	1981	158	1971	73	1961	12
2000	381	1990	262	1980	**201**	1970	59	1960	**4**

Table 4. We see in boldface the lowest number of occurrences of the term interaction in year 1960 (**4**), the increased diffusion in year 1980 (**201**), and the highest pick in year 2007 (**464**).

Then we can search more specifically for the query "subject" concerning the term interaction. It evidently changes a lot as compared to the 10.323

results we had for the simple word (that may also include repetition in a same article or in a book) we now have 3100 occurrences specifically having the term interaction for “subject”. Nonetheless, the proportion of occurrences in years and disciplines, though less spectacular, shows a correspondence with previous data. We add more sources to the inquiry comparing these data with the *New York Public Library*. I should say that the problem of different cataloging characterizations and schemes for the query in the catalog of different libraries generates some difficulties. There are 4157 results for the term interaction of which:

- 1798 are for the “subject”
- 1753 are for the “title” and
- 98 are for the “author”

While concerning the format of the editions we find:

- 3259 books/texts
- 559 microforms
- 86 web sources
- 55 DVD/films
- 53 slides etc.

Another characterization concerns the age of the reader or the user:

- 4092 are for adults
- 16 are for young adults and
- 51 are for children

If we briefly analyze all these different sources we can identify some main characteristics. Our first reference is the *British Library* table 1 in which we underlined diffusion through years. With the query of the simple word “interaction” we notice that there are:

- 3000 publications in the two-thousands
- 3000 in the nineties

- 2300 in the eighties
- 1300 in the seventies
- 350 in the sixties
- 70 in the fifties

Concerning table 1 the smallest number of results is year 1960 with 4 publications; the largest is 2007 with 464 publications. Analyzing the data we see the average is:

- 2000s: 372.2 per year
- 1990s: 313.2 per year
- 1980s: 234 per year
- 1970s: 153 per year
- 1960s: 23.5 per year

If we move then to the *New York Public Library* the average is:

- 2000s: 104
- 1990s: 116.5
- 1980s: 70.5
- 1970s: 42.5
- 1960s: 14
- 1950s: 2.5
- 1940s: 3.5 (6 years only)
- 1930s: 1.5 (in 9 years)
- 1920s: 1.5 (in 5 years)
- 1910s: 1 (in 5 years)
- 1900s: 1 (in 2 years)
- in 1873
- in 1865
- in 1850

Data are nonetheless similar between the two public libraries and there is a sort of correspondence in the increased use of the term through years. We can add an element, for instance the change of the diffusion regarding the subjects in different epochs. It seems that in some disciplines such as chemistry and physics the diffusion is more stable, because years 80s and 90s are very similar with an average of 80 per year, while in the 2000s the term is much less widespread with an average of 35.5 in the two disciplines. In psychology, where there also is the record of occurrence (573), the average has increased towards years 90s and 2000s with 93.5 results. This typology of growth and diffusion is the most common, with the exception of literature and anthropology where “interaction” does not appear at all. We can finally underline the case of the discipline of media where there is a much more remarkable and specific increase in the 2000s:

- 22 in the 80s
- 27 in the 90s
- 80 in the 2000s

This resembles data in Computer Science:

- 16 in the 80s
- 26 in the 90s
- 40 in the 2000s

A result that we particularly want to put in evidence is biology, which is similar to this general average:

- 38 in the 1980s
- 68 in the 1990s
- 53 in the 2000s

3.

If we put these elements together, they suggest us an evolution of the term “interaction” particularly during the last twenty years. I may call this an “epistemological fracture” à la Bachelard, or more exactly, with a technical expression of biology, an "exaptation"[5]. Exaptation is a term firstly used by Gould and Vrba (1982) to explain shifts in the function of a trait during evolution: in particular the fact that an organ might not have developed in order to express a specific function, but rather might have been employed to do it only later. That is why the *ex-post* adaptation becomes properly an *ex-aptation*. We may simply stress that this work will proceed considering the *epistemological exaptations* of the concept of interaction.

From this theoretical sketch I think that the history of the term in its adult life shows explicitly much more than in its very beginning. As every chronicler knows, anyhow, we should recognize that one always goes back in the history of somebody or something only when he or it has already gained its success. This looks to be the case! So, together with an analysis within this specific point of view, which focuses on the last twenty years, we shall go back to the origin of the concept to see if there is something in the ancient point of view that can retroactively shed light on our research.

> 34- Historia abscondita (hidden history) – every great human being exerts a retroactive force: for his sake all of history is put on the scale again, and a thousand secrets of the past crawl out of their hiding places – into his sunshine. There is no telling what may yet become a part of history. Maybe the past is still essentially undiscovered! So many retroactive forces are still needed! Nietzsche (2001), p. 53-54[6].

In the first place, we need to look at which kind of influences and possible transformations can be traced in the development of the concept of interaction over the last years. In particular, we will focus on the theoretical connection of the concept between the main disciplines that originally made use of it and gave rise to the standard term of reference, especially physics and psychology (chapter one). In the second place we

---

[5] Gould, S.J., Vrba E.S. (1982), "Exaptation, a missing term in the science of form". *Paleobiology*, 8(1): 4-15.

[6] Nietzsche F. (2001), *The gay science*, (ed. by) Williams B., Cambridge University Press, Cambridge, p.53-54 (ed. or. 1882, p. 64).

will try to observe the "exaptation" which has been made in biology (chapter two).
We will put in evidence that there are two main possible references to the concept of interaction. One, which we may call ordinary or spoken; even if it does not employ the actual term nonetheless it stands in the same family characterization of the concept which includes intervene, interplay, act together, react, cooperate, ... Another reference which is the use of the precise term interaction; this seems to have developed mostly in recent years, as we put in evidence in the figures. Thus we could observe that there is a *more ancient history* of the concept which despite not being expressed directly in the term, is spread in its semantic area: here we should include our traditional understanding and use of the concept which is similar to other verbs such as "to intervene", "to interplay", "to act together", "to react", "to cooperate" and so on. On the other side, there is a more recent epistemological history which delineates the precise term more specifically. Going further in this analysis we see that nonetheless in both (hi)stories of the concept (the semantic area and its precise characterization) there have always been two main directions of development and explanation: one that refers back to *linear causality* (one cause for one effect and vice versa) and another that encompasses multi-factorial causality.
In underlying this, our work will put in evidence two matrices or strong points of the term interaction that puts in evidence a conceptual development of the term into two different branches: a mathematical-algebraic ground and a *Gestalt*-geometrical ground. These two points of view establish two opposed ideas and an alternative use of the concept of interaction and thus also two opposed characterizations in scientific language and in its epistemological culture. We will look at the interplay between these two matrices, resuming a sort of *Bildungsroman* of the concept of interaction. We will see there is a real interplay between terms, disciplines and ground culture, which we think is worth a look.

4.

Let us introduce here two unknown strangers of past times who, as Nietzsche suggested in the above quote, may teach us something with their "retroactive force". A very ancient employment of the word interaction that I have found is in the recent commentary of a French book by Oronce Fine edited in 1560 and it refers to the interaction of the moon in relation to the shadows made by the sun[7]. After great enthusiasm, I found out that it is only a recent French translation of the original Latin term *interpositione* that is mentioned in figure n°Vz. 906. Anyhow, I find interesting that this very translation, "interaction" has been chosen and not, for instance, the more literal "interposition"; this is likely due to the present diffusion of the term, as we have noticed above. However we may learn some useful things about the ground of development of the idea of interaction going back to the 15th and the 16th centuries.

Oronce Fine (1494-1555) was First Professor of mathematics at the *Collège Royal de Paris* at the time of François I, but also geographer, astrologist and composer; as the well-known image we have of the Renaissance savant. We have found some references to him in an article by another remarkable unknown, Lucien Gallois, who was a professor of geography and particularly a historian at the Sorbonne at the beginning of the First World War[8].

> [...] En attirant l'attention sur ce document, nous aurons aussi l'occasion de faire revivre un savant trop peu connu, l'ancêtre des géographes

---

[7] Gallica: Vz 906. Fig. en reg. p. 44 : "L'interaction de la lune par rapport aux ombres portées par le soleil". Illustrations, *Abrégé des préceptes d'Algèbre* par J. de Billy. Sphaerae Mundi. *De Solirabus*, de Fine. *Quadrati geometricus* de Jean Demerlierium. De usu geometriae de Jacob Pelletan/; Oronce Fine, J. De Billy, Jean Demerlierium et Jacob Pelletan, aut. du texte, éd. J. Fine.

[8] We have here a quote of his Necrology by R. Blanchard: "Lucien Gallois dans la sienne ne put aborder la géographie que par le biais de l'histoire, en étudiant les Géographes allemands de la Renaissance. Il avait d'ailleurs pris goût, avec sa conscience ordinaire, à cette fréquentation obligatoire; il était devenu un excellent historien de la géographie, qui faisait autorité dans les problèmes se rapportant au mouvement scientifique qui a abouti à la découverte de l'Amérique. C'est à ce genre de préoccupations que nous devons l'excellent article sur Oronce Fine, géographe briançonnais, qu'il a bien voulu donner en 1918 à la *Revue de Géographie alpine*" ("Necrologie: M. Lucien Gallois", *Revue de Géographie alpine*, 1941, 29-3: 505-512).

> dauphinois, qui fut en France, au début du XVI siècle, l'un des meilleurs ouvriers de la géographie. [...] C'est par les mathématiques qu'il fut amené à la géographie. Il est à peine besoin de dire que la géographie ne tenait alors qu'une bien petite place dans le cycle des études; elle y figurait cependant, mais comme dépendance de l'astronomie, et voici par quelle sorte de conséquence logique. La terre fait partie du système solaire. Les astronomes la regardaient donc comme étant de leur domaine. Ils l'étudiaient après avoir étudié les astres. Gallois, (1918), p. 2-3.
>
> [...] Il est le premier en France qui ait figuré sur des mappemondes les continents nouveaux, qui ait essayé de coordonner les renseignements fournis par les navigateurs, qui ait répandu ces notions dans le public sur des cartes gravées, enjolivées de dessins qui sont des merveilles de goût. Ainsi se constituait la tradition cartographique française. Gallois, (1918), p. 3.
>
> [...] Y enseigna les mathématiques, surtout, [...] les applications de cette science à l'astronomie et à la géographie. C'est par là qu'il fonda un enseignement nouveau, dégagé de toutes les subtilités, de toutes les entraves déjà scolastique et vraiment digne de la maison dans laquelle il entrait Gallois, (1918), p. 3-4[9].

It is relevant to remark just one or two things in this portrayal which may instruct us on cultural shifts with regards to word meanings and discipline boundaries, which is one of the main epistemological themes of this inter-disciplinary research. In the quote above we are told of boundary modifications in the branches of knowledge as well as in the conception of disciplines in the 16th century. We remark that in Gallois' description, Oronce is lead to geography through mathematics. Geography, in fact, was considered a mere *part* of the more renowned astronomy, because the earth was a part of the universe. Mathematicians and astronomers, not specifically geographers, where those in charge of studying its geographical aspects too.
This creates a peculiar point of observation concerning earth matters and also with regards to conceptual frontiers and discipline boundaries. The crossing of subjects and practices was clearly perceived and theorized

[9] Gallois L. (1918),"Un géographe dauphinois: Oronce Fine et le Dauphiné sur sa carte de France de 1525", *Revue de Géographie alpine*, 6-1: 1-25.

within a theoretical ground; and let us add that it was clearly different from today's idea of interdisciplinary subjects. Is not so common today to have one organic philosophical insight that establishes the specificity of scientific practices and ideas. It is more likely that we now have a *regional conception* of sciences rather than a *global identity*. In the Renaissance the conception of the Universe –the global perspective– threw light on the more limited locus of the earth –the local perspective. The geographical aspects of earth were considered a regional and confined dimension with respect to the metaphysical one, rather than the primary dimension to be observed, as in our present theorizing of geography, but also of psychology, of biology etc. We can say then that the crossing of subjects was *internal* and at the same time *external* to the theoretical building. It was internal because the local perspective, such as geography, was a part of the bigger plan of the Universe; it was studied with the medium of such a general conception and mostly with the support of mathematics. But it was also external as it was not properly determined, but rather a specific case, a sort of exception, or an eccentric and horizontal terrene anomaly as regards to the paradigmatic vertical laws of astronomy[10]. We may add that, as is well known, the conception of the human being fell within this global view too, in an anthropocentric perspective that put the Man at the center of the Universe.

Gallois tells us another interesting fact concerning Oronce Fine which expands this ideal link between mathematics, astronomy and geography even to the more vulgar astrology. In the quote from Gallois, Kepler himself explains the success of astrology at that time in an amusing commentary:

> Les astronomes, à cette époque, étaient tous plus ou moins astrologues. Le grand Kepler, lui-même, tira toute sa vie des horoscopes, moyennant salaire, sans y attacher autrement d'importance. «Combien serait petit, disait-il, le nombre des savants qui se dévoueraient à l'astronomie, si les hommes n'avaient pas espéré lire les événements futurs dans le Ciel!»[11]. Gallois

[10] Casini, 1998.

[11] Gallois (1918), p. 7, the quote from Kepler is from Bigourdan G., *L'Astronomie. Evolution*

(1918), p. 7.

"How little would the number of scholars be who would study astronomy, if mankind did not hope to read future happenings in the sky". It is amusing to remark this connection between science and human beliefs in astrology, which was precisely the economic fund for scholars. The common ideal opposition between disciplines pictures abstract, noble and celestial mathematics (and astronomy) on one side and on the other, concrete, vulgar and mundane geography (and astrology). We see that in reality things were not so clear-cut, since in order to study noble astronomy one had to live on vulgar astrology, and since practical geography was not considered but as a part of astronomy[12]. Moreover, as Jammer remarks, it was properly the coherent structure of the thought which shaped all these crossings and interactions.

> The importance of astrology as a consistent edifice of thought for the Middle Ages cannot be overestimated for a correct appraisal of pre-Newtonian science. Jammer, 1957, p. 54

Jammer underlines the importance of astrology, intended as a coherent structure of thought, which sustained a dependency of natural phenomena on planetary movements. It is interesting to remark this as in his opinion this general hypothesis has contributed to the foundation of the *conception of causality* by means of specific positions in space that characterize certain distributions of objects. This, which we may call a "geometrical idea" of causality, is also at the basis of the modern conception of force (Jammer, 1957). As we will see later, if we think of the modern notion of field we find even more clearly this idea of causality as an interaction between simple dispositions of charged objects. With respect to the analogy of astrology above, the excitability, or the charge of different human beings and more generally of natural phenomena is the result of their position and their motion.

The Renaissance has been pivotal for many contemporary developments

des Idées et des Méthodes, Paris, 1911, p. 26.

[12] Thorndike L. (1955), "The true place of astrology in the history of science", *Isis*, 46; Paolo Rossi (1971), "Sul declino dell'astrologia agli inizi dell'età moderna", in Id. *Aspetti della rivoluzione scientifica*, Morano, Napoli.

of science and science interpretation (Casini, 1998). It began a new idea of the savant and of methodology in science. More specifically for our concern there are some remarkable ideas that work as sprouts of our "epistemological culture" and I think it is very interesting to mention some of them briefly.

Sambursky, who is a physicist and a historian, in his book *The physical world of the Greeks* (1956), remarked that at the time of the Greeks scientific culture, was not a prominent subject. The scientists were isolated from the community of savants and besides there was no scientific community that could maintain and discuss ideas. That is one of the main reason why, in Sambursky's opinion, the great change of the Renaissance conception of science transmitted an appropriated ground which was fertile enough to allow a scientific revolution. In the introduction of *Filosofia e fisica da Newton a Kant*, Casini remarks another fact. At the base of physical conception of the Greeks there was a "visual illusion" according to which the activity of the Universe was a projection of the regular and nearly circular motion of earth. Circular movements of the sky were, in reality, the annual motion of earth on its axis.

> Quando Copernico, sviluppando le antiche intuizioni dei Pitagorici, rimosse la terra dal centro del cosmo e la proiettò in un universo infinito, immettendola in un'orbita circumsolare al pari degli altri pianeti del nostro sistema, l'intero edificio peripatetico apparve destinato a crollare. Casini (1998), p. 14.

When Copernicus and later Kepler and Galileo modify the observer's point of view on surface of the earth, this illusion vanishes, and so does the separation between a celestial and a terrestrial word.

> A partire da quel primo sintomo la rivoluzione astronomica del Seicento – o la rivoluzione scientifica *tout court* – preparò un riassetto concettuale *ab imis fundamentis* della fisica, una sostituzione totale del modello cosmologico geocentrico, con tutte le sue conseguenze. Il modello cosmologico nuovo fu, in sostanza, un sistema di leggi: ma leggi questa volta, propriamente matematiche e geometriche, ossia derivate per

induzione dall'esperienza, verificate in base a esperimenti che riproducono i processi naturali, e generalizzate su base universale senza distinzione tra "terra" e "cielo". Casini (1998), p. 14.

Earth and sky were no more divided then, but at the same time earth was no longer the point of view of the Universe. Moreover the epistemological fracture has been the introduction of laws based on mathematical calculus and verified by experiments.
We may sum up some elements that we will follow and connect together with other considerations from now on.

1. Disciplines were connected by means of a general-philosophical structure.
2. Crossings of fields and boundaries were frequent and practically there was much more (implicitly) reciprocal influence of earth matters on theoretical culture and thought than one may have expected (explicitly).
3. Science became a system of geometrical and mathematical laws, derived by induction from experience, verified by means of experiments reproducing the natural processes and generalized on a universal base without any distinction between earth or sky phenomena.
4. Scientists were paid for what they produced practically (astrological predictions, technical applications) much more than for what they invented theoretically (theoretical science).
5. Which is the reflection of all this on language and on the employment of the scientific language? How is an epistemological culture active in the shaping of science and scientific thought?

5.

We can delineate three main fields which have been the cradle of the development of the concept of interaction starting from the half of the mid-20th century: physics, chemistry and psychology.

In chapter one we will make reference in particular to physics and psychology to see their specific definition of interaction. We have chosen among the three subjects the two presenting a wider spectrum in their interplay, as chemistry has many points in common in the study of physics, while psychology has introduced completely new instruments of analysis. We consider one main representative science such as physics on behalf of "natural sciences" and one major science on behalf of "spiritual sciences". As Wundt said:

> Donde due vie si svolgono per lo studio dell'esperienza. L'una è quella della scienza naturale, che considera gli oggetti dell'esperienza nella loro natura, pensata indipendentemente dal soggetto; l'altra è quella della psicologia; essa investiga l'intero contenuto dell'esperienza nella sua relazione col soggetto e nelle qualità, che sono immediatamente attribuite ad esso dal soggetto. Wundt (1896) [13].

After this, in chapter two we will focus on the crossed elements of the concept of interaction enlightened I chapter one. In particular we will observe the features which we find operating as sources of meaning in the representation of the concept proper to biology, by means of their inter-actions and inter-reactions. In other words, starting from an epistemological standpoint we will try to delineate another history of the concept, which is conceptual-evolutionary and not only historical; or as we said we will see the epistemological exaptation of the concept of interaction. This (hi)story is made up itself of an interaction between fields, affinities, researches, culture and *Zeitgeist*. The main question that will rest as a ground of our investigation is: what determines a use and an abuse of a concept? Therefore, we will focus on some specific examples of research fields where interaction becomes a key aspect. And as we said, we will highlight in particular two opposed use of the concept, an algebraic one and a *Gestalt*-geometrical one. This will allow us to propose some clarifications and also some heuristic examples that we hope may be someway useful for today's theoretical and modeling

[13] *Grundriss der Psychologie*, Engelmann, Leipzig.

researches *about* interaction in biology, but *also* with “a twist of interaction”.

As a result of this direct interaction, this work will try to put in evidence a possible use and abuse of the term. Some questions that we propose to focus on are: what exactly is an exaptation of concepts from one discipline to another? And which are its consequences? Which kinds of influences are at the base of a shifting of concepts in science? And which influence may establish reification and disrupt the inner potentiality of a development in language and thought?

Chapter one

Interaction through matters and times: physics and psychology

The physical world

1.

This book has been edited in the innermost conviction that physics has a message for philosophy inasmuch philosophical reflections are apt
to fertilize physical thought.
Max Jammer[14]

Pour cesser de frétiller de façon bouffonne dans les filet des concepts admis, il faut commencer par en dénouer les entrelacements et en dissocier les fils [...] Il faut éviter d'associer a' la théorie un vocabulaire laissant entendre qu'on sait d'avance sur quoi elle porte, car cela même ne va pas de soi.
Michel Bitbol15

In physics the capital references to interaction are fundamental interactions, which are related to the four basic forces of physics — gravitational, electromagnetic, strong, and weak—. These forces

> govern how objects or particles *interact* and how certain particles decay. *All the known forces of nature can be traced to these fundamental*

[14]"Questo libro è stato scritto nella profonda convinzione che la fisica contenga un messaggio per la filosofia nello stesso modo in cui le riflessioni filosofiche sono idonee a fecondare il pensiero fisico", "Prefazione all'edizione italiana del 1971", *Concepts of force. A study in the foundation of dynamics*, Harvard University Press, 1957. English translation is ours.
[15] Bitbol (2008) Introduction, p. 7.

> *interactions*. The fundamental interactions are characterized on the basis of the following four criteria: the types of particles that experience the force, the relative strength of the force, the range over which the force is effective, and the nature of the particles that mediate the force (*Encyclopedia Britannica*, "Fundamental interaction", our italics).

As we see from this general definition 1., in physics fundamental interactions are directly connected to the concept of force. In particular there is a sort of equality between force and interaction, as the forces "govern how particle interact", and because interactions are characterized on the basis of force, in a crossed correspondence. In this equivalence, we are not straightaway able to say whether "force" is the basal concept or rather "interaction", nonetheless for the moment we can underline this evident connection. We should remark that by now we are trying to do an analysis of the concepts involved in this general definition of physics, without taking into account the historical perspective, which we will recuperate later on along our way.
In the definition above, the four forces describe the action of particles interacting each other (or also decay): these forces
govern how objects or particles *interact* and how certain particles decay. Thus the very explanation of the definition turns from the subject (of the definition), the notion of "fundamental interaction", into a verb, " to interact", that concerns directly the *action* of particles the one with the other. So the concept, interaction, rebounds onto the verb, to interact, they integrate and interplay in the same family of concepts. We note that in this correspondence the notion of force, as well as that of interaction, is defined on the basis of the *action* of particles one with the other. Then, reading again the definition above, it intuitively comes to mind to ask if we need at least *two* particles to have an interaction (or a force), excluding particles that decay. We may read then from Feynman's lesson:

> For example, in dealing with force the tacit assumption is always made that the force is equal to zero unless some physical body is present, that if we find a force that is not equal to zero we also find something in the neighborhood that is a source of the force. [...] One of the most important characteristics of force is that it has a material origin, and this

is not just a definition. Feynman (2007), 12-2.

Here in Feynman's definition we remark the notion of source of the force, the material origin, as the imperative characteristic for having an amount of the force *different from zero*. By definition 1 above, staying in the equality of force and interaction, the characteristics specified for force should be valid also for interaction. So it should be applicable that also to have an interaction one needs at least a source or a material origin of interaction and thus *two* distinct "objects" not yet specified. One object, for instance, that receive the force and another that is the source of the force. With this description we may sum up a picture of a world where nothing ever happens to things alone. It is a pluralistic world. Objects are in condition to exercise and carry a force, act and react only when elicited by the presence of something else.

Replacing objects with particles in the example above, we can say that one particle alone could not act nor interact. There is one exception that we have to mention straightaway, which is a particle that decays. Does the particle that decay specifically act, interact or react? We see that the answer to this question is connected to our interrogation on interaction – what is physically an interaction? Is it an action, a force, an interaction or a reaction?– and it necessarily requires a specific point of view on both questions that are intrinsically linked.

In order to get a possible answer we should resume a bit our picture trying to see all the elements we have. The main characteristics put in evidence till now are:

- Force and interaction seem to be used as equivalent and replaceable elements.
- They both involve the action of objects or particles the one with the other.
- To have a force or an interaction one needs at least a source, or a material origin and another object, in a pluralistic world.
- This general physical picture underlines the fact that force and interaction seem to be in the same family concept of the verb to interact and to intervene, all requiring the general idea of an *action* going on between objects or particles.

Even if the questions above may seem trivial (what is physically an interaction? Is it an action, a force, an interaction or a reaction? and does the particle that decay specifically act, interact or react?), we hope that our purpose is unambiguous: if the notion of “interaction” is so similar to that of “force” and for instance might be morally substituted with the verb “action”, why has it become such an influent and fundamental term, such as we have seen in previous section? With regards to the verb “to act” is there something more in the concept of interaction? Is there something that pictures in a better way the descriptions of our more and more intricate analysis of our complex world?

This problem requires necessarily a better understanding of the Gordian family of concepts that we have seen interplaying till now made by the relationships between particle, force, to act, to interact (and to react).

2.

Let us start with the first element. What do we mean when we say particle? The term in classical physics is used to mean those particles that do not have a substructure16. To everybody here comes into mind the notion of atom. Named to mean exactly “what cannot be divided”, the term comes from early philosophy (Leucippus of Miletus V sec. BC) lands in modern physics and is currently used in scientific vocabulary. The origin of the idea of atom has interested many and has different interpreters. One point in common of many hypotheses that we want to enlighten is focusing on the antithesis of the categories of being and not being and its concrete expression in the categories of full and empty and identity and plurality. In this way we may call the atom the mechanic aggregate of the solution of these antitheses. Atoms and their activity by means of their aggregation, express the possibility of being with regards to the constitution of plurality. Moreover they determine found the

[16] For the dispute about the matter-wave duality see further on our discussion on complementarity principle.

possibility of emptiness, such as the space of interval between atoms. If you allow a phrase which does not sound very well: being is no more only one, but can be many. And the constitution of matter, the form and the movement are delineated all together in one whole theory. We need to look at this very notions which underpins the intricate conceptual (hi)story of the idea of interaction.
I have chosen between many books on the subject a peculiar lineage which is traced back in the fifties. In fact in physics in this period the great discoveries of the beginning of the 19^{th} century (such as atom's decay, the notion of field, and the quantum revolution) lead the concepts we are dealing with such as particle, force and interaction to be looked upon in new and different ways (Heisenberg, 1958). I think that for our epistemological research on the sprouts of the concept of interaction this peculiar period may be very instructive for us reflecting these question in their most fresh look. Thus we will refer especially to this conceptual womb of the fifties looking especially at their way to consider the formation of the idea of atoms and particle. We will sum up briefly and without any presumption of historical completeness some elements which can help us to better delineate the difference that we have mentioned before between the notion of force, that of action and interaction.
Samuel Sambursky, who is an historician of physical thought explains that the notion of atom probably comes out to give account of Eleatic school's paradoxes (Sambursky, 1956), such as the paradox of divisibility. This paradox states that it does not exist a limit to every mathematical division, such as the division in two, so, for instance, the number of points between two points is infinite (Zenone's paradox)[17]. That is why then, the first postulate of the atomist theory is the atom, a sort of "physical limit" to the infinite division of the matter; it puts a boundary between the infinite *mathematical* division and the *physical* one. As we have mentioned above, this explanation might have suggested also a solution to the traditional antithesis between the unity of the

[17] For a critic on the Zenon's paradox and on the Eleatic school, see Giannantoni, 1976. For a specific physicist look see Schrodinger's book *Nature and the Greeks and Science and Humanism*, Cambridge University Press , Cambridge,1996.

Cosmos and the plurality of its phenomena, or to the permanence of the plurality.
The picture that emerges shows on one side there is the monistic view by Taletes and then by Parmenides, which reached fever pitch and arrived to forbid every possibility to movement. On the other side there were Empedocles and Anassagora that stood for a pluralistic vision of phenomena. The atomist theory in the light of Sambursky is a sort of synthesis of these visions.

> Unless there is void with separate being of its own, “what is” cannot be moved – nor again can it be “many” since there is nothing to keep things apart (Arist., *De Gen. et Corr.*, 325a,[72] p. 108).

The notion of atom brings with itself also a second postulate that of emptiness, which grants the possibility of movement mechanism. In the fifth century BC Democritus of Abdera (born in 460 BC) a disciple of Leucippus and then especially Epicurus of Samos gave to the atomist theory an established philosophical system. We do not have scripts from this period except the quotes by Aristotle and Theophrastus in their dispute against the Atomists. Only later on the Latin philosopher Lucretius, in the first century BC, hands down the atomist tradition in its famous poem *De Rerum Natura*.

> Democritus and Leucippus say that there are invisible bodies, infinite both in number and in the varieties of their shapes, of which everything else is composed – the compounds differing one from another according to the shapes, positions, and groupings of their constituents (Arist., *De Gen. et Corr.*, 314a [74], p. 110).

> The atoms are differentiated by their shapes: the nature of them all is, they say, the same, just as if, e.g. each one separately were a piece of gold (Arist., *De Caelo*, 303a[73] p. 110).

As the atomist theory was based on monist basis (the matter is one) and mechanical concepts (aggregation through emptiness), the atoms were conceived all of a same matter and their different characters were the result of geometrical and mechanical combinations.

> They have all sorts of shapes and appearances and different sizes... Some are rough, some hook-shaped, some concave, some convex and some have other innumerable variations. (Simpl. *De Caelo*, 294, 33 (D68A37)[95] p. 110-111).

Epicurus adds also a superior limit to the number of atoms and a specific weight, which in Democritus was just function of the volume of the atom (eccedenza, its weight surplus, Simpl. *De Caelo*, 294, 33 (D68A37, p. 124). In Epicurus' conception, the weight, and not the shape-geometrical criterion (stereoplasticity) is the reason for different atoms to move and get together. We have then two different possibilities: one by Democritus that is based on volume and shape of the atoms and another one by Epicurus which is based on weight such as the impulse of the movement.

> Democritus recognized only two basic properties of the atom: size and shape. But Epicurus added weight as a third. For, according to him, the bodies move by necessity through the force of weight. (Aet. I, 3, D68A47[97] p. 111).

In the following passage from Simplicius, the annotator of Aristotle, we find all together the characteristics proper to every atom and to their predetermined movement, in a sort of a first elementary cinematic theory.

> These atoms, which are separated from each other in the infinite void and distinguished from each other in shape, size, position and arrangement, move in the void, overtake each other and collide. Some of them rebound in random directions, while others interlock because of the symmetry of their shapes, sizes, positions and arrangements, and remain together. This was how compound bodies were begun. (Simpl. *De Caelo*, 242, 15 (D67A14)[75] p. 113).

It is evident that not every atom could get together with all the others. It is their "casual interaction" of form, dimension, order, position (and weight) that happens to put them together.

> As a result of their movement they strike each other and get caught in an entanglement which brings them in contact with each other and makes them come very close together. But any real unity is not formed out of them. That would be an utterly foolish opinion, since two or many things

> can never become one... IN his opinion, they hold out and remain together until some stronger force acts upon them from outside, shaking them and scattering them (Simpl. *De Caelo*, 294, 33 (D68A37)[95], p. 114).

Every atom keeps a sort of identity even in the combinations with the others. In fact, nothing allows creating a "unique nature": atoms get together by collisions and they could be separated again only thanks to the aid of an external force.

> According to this view the primary magnitudes are infinite in number and not divisible in magnitude. Generation is neither of many out of one, nor of one out of many, but consists entirely in the combination and in the entanglement of these bodies. In a way these thinkers too are saying that everything that exists is numbers, or evolved from numbers (Arist. *De Caelo*, 303a[76], p. 113).

We remark two things: the first is this idea of collision that originates bodies via combination and aggregation, a sort of *primordial concept of fundamental interaction* that we are dealing with. The second is enlightening the principles of identity, position and quantity by mean of the atom. It emerges that the atomist theory enlightened this sort of *minima mundi* based on simple rules and their interplay by which atoms are conceived with regards to their quantity, position, possibility of movement, thus ways of aggregation. In this perspective “things are numbers and are made of numbers” as reported by Aristotle. We will see in third section how the discipline of Ludics may have some similarity with this minimal approach by which the world of reference is described starting only with a *locus* and its *number* (*Locus solum*, Girard, 2000).
We may stress that here there are two different ideas which are both involved in the atomic theory and that come out: one that is based on cinematic movements, aggregation and interplay between particles and another one which is more focused on determination, identity and quantification.

3.

It's interesting to mention another thing that Sambursky enlightens in his book *The physical world of the Greeks* mentioned above. This will allow us to make a commentary which correlates the vision of a “cosmos of interactions” with the scientific world and its practices. Sambursky remarks a relation between the absence of studies on random phenomena and the limited development of mechanical-physical sciences at the time of the ancient Greeks (Ivi, chapter iii). Even looking at more recent studies, for what we know, there were not investigations on randomness in antiquity[18]. The first book of antiquity that poses questions specifically on probability is *De Ludis* by Cardano in the half of XVI century. In Sambursky's opinion it is strange that in Greece, where playing games was a common activity and where betting was frequent, there was not an interest in randomness phenomena. As Sambursky remarks bets were made only on one-throw per time and they were based entirely on the immediate ability of the player. There were not collections of throws made during the game that may allow considering a probability analysis. Besides that, in spite of the great Egyptians' mechanical-applicative development, the Greeks, with their reputation of aristocrats and lovers of theoretical thought, do no seem to have worked especially in physical sciences and applications. Nevertheless we should not forget the great contributes in astronomy, mathematics and geometry, for instance made by Archimedes in the Hellenistic time. There is another tradition that one should mention, even if it is not possible to enter in details, which enlightens the ability of the Hellenistic scientific revolution that has been undermined by Middle Ages culture (Russo, 1997).

One may illuminate a fracture between the powerful development of rational thought and scientific activity on one side and on the other experimental applications (such as precise measure instruments and machines). Sambursky's thesis is that the same philosophical movement that on one side helped founding the pillars of philosophy and science,

[18] For an elaborate history of science at Greeks time see (Russo, 1997; Wolpert, 1993)

on the other side prevented quantitative and structured science to be established. In fact, physical sciences were based on the philosophical conception of the Cosmos as an *organism*, the Order or the Nature that includes all events and should be behold and understood as a *whole body*. This conception based on simple very *natural* observation inhibited creating or recreating *unnatural* events as the scientific experiments are. It is very interesting to put into light this opposition between a natural consideration and the impossibility of undergoing a non-natural attitude, such as science, necessarily entails. This means *only* that the perfect experimental "natural" environment, such cyclical astronomic events, were the ones studied. On the contrary, opening and de-structuring what has a structure in itself, such as a whole body, to create a detached point of observation and make an experiment it was considered an unnatural attitude. In other words, it would have been such as cutting a hand from a living body to see how it does works!

> While we attempt to transform the world into an abstract mathematical entity which transgresses the boundaries of the inorganic universe and infiltrates into biology and the realm of man, the Greeks saw the cosmos as a living organism,a s a projection of man into the distances of the outer world. (Preface, p. v.).

> From this time on, a picture of the cosmos evolved that must be set against the background of a civilization based on an interplay of science and technology, while the cosmos of the Greeks emerged from a world whose scientific curiosity remained untouched by any desire to conquer nature (ibidem).

In the understanding and theorizing of the Greeks the entire Cosmos was considered the proper organized element or "Gestalt" to rely on. This means a living order, the preservation of which was included in the harmony of the system itself. It is very interesting in our consideration the coincidence within this *Gestalt* perspective which may, as a red line, delineate a proper field of researchers and of thought. As we will see more in detail in next section Köhler reminds that the expression *Gestalt* was used in Goethe's works for representing the idea of the concrete entity in itself, the entire which brings and produces the same qualities

that form it.
One may quote on this subject a very stimulating article by Schuhl, a philosopher and an historian of ancient thought.

> La Nature forme un tout qui s'explique, pour ces viex penseurs, ou technologiquement ou biologiquement. L'eau de Thales est le liquide fecond d'ou nait la vie; le feu d'Heraclite sera pour un large part la chaleur de l'ame, l'air d'Anaximene est [...] ce souffle qui [...] "De meme que notre ame, qui est faite d'air, nous mantient, de la meme facon, le Cosmos tout entier, c'est le pneuma, qui est de l'air, qui l'entoure", mais qui en l'entourant le soutient (AET, I, 3, 4; Diels, Vors., 3B2). Schuhl (1952), pp. 197-221.

In particular one may add that the interaction between the parts and the whole is the fundamental intuition of biological science, which has been pointed out especially by Hippocrates and his school (Schuhl, 1952). We may notice in this peculiar trait a natural-harmonic approach which constitutes a trend that from then till now has had its own history of high and falls such as in the Renaissance and in the Romanticism (Thomas, 1983)19. Goethe was one of the most famous advocates of this integration of parts functions within an individual "as integral to a total design that confers character, and specific function on each constituent" (Tauber, 1994, p. 29).

> Each living creature is a complex, not a unit; even when it appears to be an individual, it nevertheless remains an aggregation of living and independent parts. Goethe (1989), p. 2420.

More recently we find this systemic view on nature in James Lovelock's Gaia hypothesis in 1979[21], by which the entire world is seen as a single ecosystem, an

> all encompassing organismal entity constantly adjusting to the vicissitudes of global climatic and geological change, is but the latest

[19]Thomas K., 1983, *Man and the natural world. A history of the modern sensibility*, Pantheon books, New York.
[20]Goethe J.W., 1989, Goethe's botanical writings, Ox Bow Press, Woodbridge.
[21] Lovelock J. (1979), *Gaia. A new look at life on earth,* Oxford University Press, Oxford.

vision of the organism in balance, and accountable to its generalized environment and coordinated interactions, even far removed from its immediate concern (Schneider, Boston, 1991)22. Tauber (1994), p. 29.

We underline this because in our discussion we will refer to this organic-conception as one of the two matrices-ideas operating in the development of the concept of interaction. We clearly remark here the interaction of culture, thought and science in one epistemological lineage that serves as the ground of germination of concepts. We have mentioned in the introduction the role of the epistemological culture behind science and scientific language. In this field the importance of the study on metaphors is a keen instrument for becoming aware of the epistemological culture behind and inside science practices (FoxKeller, 2006; Sontag, 1977; Hesse 1963, Black, 1962; Gagliasso, 2003; Frezza, 2010).

4.

As we have seen the atomist theory puts in evidence the importance of the principle of quantity, which we have said that is a specific generator of identity, number and determination ideas. The atom and its movement collects together the principles of multitude, infinite, hazard, determinism, and causality. But, nonetheless as we have mentioned one should remark the absence of the analysis of periodicity and chaos events. This leads to the general conception of the atomist theory as pure mechanicist and monistic. Nevertheless in our opinion it is remarkable the Atomists'idea of a *whole entity* that seems to "emerge" from these random activities:

> In this connection there is one fact that need occasion no surprise. Although all the atoms are in motion, their totality appears to stand totally motionless... This is because the atoms all lie far below the range of our senses. Since they are themselves invisible their movements also must elude observation. Indeed, even visible objects, when set at a

[22] Schneider S.H., Boston P.J. (1991), *Scientist of Gaia*, MIT Press, Cambridge.

> distance, often disguise their movements. Often on a hillside fleecy sheep's, as they crop their lush pasture, creep slowly onward, lured this way or that by grass that sparkles with fresh dew, while the full-fed lambs gaily frisk and butt. And yet, when we gaze from a distance, we see only a blurb – a white patch stationary on the green hillside (Lucr. *De rerum nat.*, II, 308-322[249] p. 115).

Here we have of course in different terms the description of a *chaotic* group of particles that appears as one *stable* entity *at our level of phenomenality*.

There are two facts which are present here that we want to underline. On one side there is the traditional idea of the fallacy of the senses, which is the prejudice of sensibility and hearth matters versus rationality and celestial world, for instance such as in the traditional Platonic lecture[23]. On the other side we clearly remark the distinction between different levels of reality and such as things seems and such as things are. This is a far too wide argument of philosophical reflections for our modest research and it involves some of the most famous names of the history of philosophy such as Kant, Schopenhauer, Husserl, Wittgenstein. We cannot enter in this debate, nonetheless we want to consider the main idea that there are proper unities of analysis for distinct phenomena at different levels of phenomenality or special *Gestalten* of analysis as we will better see in next section.

Going back to atomic theory, we were saying that it is one of the first theory that correlates movement, causality, determinism, randomness and that has rudimentary ideas of mechanical collisions, of impulse and force by the media of a mechanical law. As well known, Epicurus introduced an impulse –the *παρένκλισις* or in Lucretius' Latin, *clinamen*– to make starting the movement, establishing a shift from the pure mechanical laws of his predecessors[24]. According to Leucippus and Democritus, in fact, the movement of atoms was *a fact*, just an element of the *deterministic-mechanical* theory chain. The shift inaugurated by

[23] For a synthesis of this theme about Platonic philosophy see for instance (Ross, 1951)

[24] The only fragment in Greek about this notion is from the Oenoanda inscription (fr. 54 in Smith's edition). The famous reference is in Lucretius's *On the nature of things*, II, 216-224 and 284-293. Lucretius, *De Rerum Natura*, (ed.) W. Ellery Leonard, E. P. Dutton, Boston, 1916.

Epicurus introduces a gap in the mechanical chain of events and launch in the theory a question about the *how* of the events and *why* particles encounter each other, act and react upon others. The *παρένκλισις* is expressly introduced to grant a *reason* of atoms' interaction. Here we do not mention all the other questions about human activity and free will coming out from this little revolution[25].

5.

From the elements we have gathered till now we know that the interaction concept links back to the concept of force, which essentially establishes a dynamic between objects. This dynamic is properly an action that "moves" particles. The notion of particle is fairly ancient and the atomists have told us this entire story the actors of which are matter, atoms, movements, collisions, chance and causality. In this (hi)story the concept of interaction, even if not literally present, is there, it contains in itself a principle of action between two distinct objects and it is made of this very action such as an inter-action. In a sense we may intend that the concept of interaction is what it is all about when we talk about force, particles and atoms.
We know also that an action never happens properly to an isolated particle, considered alone in the universe. So we pose our question: is there in the simple notion of action something that confers per se such a dimension of plurality and coordination between agents, parts, and particles? Nowadays we have many linguistic possibilities to mention this property such as "reciprocal action", "to act one with the other", "to act together", "to integrate", etc. But how has to be interpreted the meaning of the world "action" in itself? Without even knowing what do we exactly mean when we mention the term "action", for the moment we may just roughly hypothesize that to enlighten that an action implies at least two things one has consider the possibility of adding the suffix "inter". This preposition alludes to the constitution of a sort of *bridge* in

[25] For a comment on free will and moral determination see (De Caro, Mori, Spinelli, 2011).

the action; an action that does not rest on itself, but passes and goes through something else, is involved in other.
Then our question could be: Why? Why do we have to enlighten with a specific word that an action implies at least two things and that ingenerates a communication a bridge between these two distinct things? Perhaps because it allows to glimpse directly the plurality of our world of reference. It is an action that becomes an interaction. Nonetheless we still have to decide the priorities in this new world of interaction. We would have to decide whether it is a Kingdom or if we have a sort of democracy or complete anarchy or whatever else.
For the moment, staying out of this world that we do not seem to know enough, we may suppose that if interaction has become such a common term is because we specifically want to mean something about action but differently or more precisely than the word action in itself. Something that was there in the concept of action, but that at the same time was not. For instance, as we have already mentioned, in his book *The origin of species*, Darwin does not use the term interaction, even if he uses six times the verb "to intervene", which beholds to the same family of concepts of interaction.
Should we make the hypothesis that a moment has come when the maturity of a different epistemological culture has started to make reference directly to the term "interaction" in spite of the simple “action”? Is that a sort of new paradigm, referring to Khun’s terminology (1962)? Which is its convenience? Do we have a need for a pluralistic and complex explication of the world the solution of which comes allowing the concept of interaction to have its legitimate use and domain?
Here we are not able to present such a strong thesis, of a paradigm, but we are trying to underline the interplay between two different ways to refer to the concept of interaction: a deterministic and an organic one. We can make a sort of imaginary correspondence with the Greeks dispute, hinted above, between monist-deterministic and pluralistic-random conception. We said that the concept of interaction necessarily establishes a pluralistic world, but inside the "pluralistic" concept of

interaction itself we see two main matrices: a "monist", a linear-deterministic trend and a "pluralist", a geometrical-non deterministic tendency. Because we cannot say how these two branches would develop, we are nonetheless trying to imagine and analyze how they took form: if they have a common root, or if they may have a different father or if they have always been beloved twins. We may also think if they are such as the double-faced Janus (*Janus Bifron*) represented with a double-faced head, each looking in opposite directions: one that looks inside the house or the city and the other that keep an eye on what happens outside.

6.

Going back to definition 1. of "Fundamental interactions" (by which they are "Forces that govern how objects or particles *interact* and how certain particles decay and *all the known forces of nature can be traced to these fundamental interactions*") we have remarked that such a simple and fundamental concept of physics needs a very fine analysis. Another commentary is that in definition 1. we are meant to relate force and interaction, but we do not seem to be able figuring out the precise correlation. As a matter of fact, we are left with these kind of questions: Is every force an interaction? And is every interaction a force? Does a force act or interact?

One may even hint a possible "metaphysical" temptation in the physical definition of fundamental interactions. For instance, in its correlated problems such as: If "*All the known forces of nature can be traced to these fundamental interactions*" what can these fundamental interactions be traced to? Which is the fundamental element? Is that the interaction itself? Do we have one theory that explains the physical-philosophical basis of matter? Yet again, if one takes into account the Greeks dispute on atomism, what kind of opposition there is between the atomist mechanical-deterministic theory about matter and the organic-holistic one? Or in nowadays term, how does the analytical approach oppose to the synthetic one? And from this very standpoint where does the concept of interaction stand: in the deterministic or in the holistic perspective?

These are all the questions we are trying to face, making them becoming explicit in our epistemological query. We have started to point out the ground of development of the concept of interaction, which rather than absolute seems polar (mechanic and organic, analytic and synthetic, deterministic and multifactorial). Its polarity seems to be constitutive of its proper determination.

We need to emphasize the temptation of metaphysics in the physical definition concerning fundamental interactions as well as other basal notion (matter, force, particle...). In fact just as Feynman's student in the quotation below, we are continuously and desperately questing for precise and *complete* definitions[26]. And this will of extension over the physical interrogation is not so surprising, even if not legitimate in Kantian terms, because, as we have seen, such questioning about foundations existed at the time of the Greeks and probably would never change here after[27].

> I do not like this imprecision, I should like to have everything defined exactly; in fact, it says in some books that any science is an exact subject, in which *everything* is defined". If you insist upon a precise definition of force, you will never get it! First, because Newton's Second Law is not exact, and second, because in order to understand physical laws you must understand that they are all *some kind of approximation*. Feynman (2007), p. 12-2.

This kind of approximation as a rule for science (and even as conduct for life) may be very interesting[28]. What Feynman requires to the *rigorous* study of physics, the claiming of its approximation, conversely requires an opening towards some *approximate* disciplines par excellence such as philosophical investigation and epistemology. I personally support, and of course in this I just follow the lines of more preeminent scholars (e.g. Jammer, 1957; Hesse, 1963) what Sambursky found the negative aspect of Greek conception of science: the mix between (philosophical) thought

---

[26] For a critic on the relevancy of negative results in the history of science see (Longo, 2008).

[27] The question of foundations is another "big" topic of philosophy and science. An interesting meeting on the subject has taken place in Paris, November the 18^{th}-20^{th}, "The question of foundations at a post-foundational epoch ".

[28] See, Chalmers A., *What is this thing called science? An assessment of the nature and status of science and its methods*, Univ. of Queensland Press, St Lucia, 1976.

and science. In Geymonat's words, from the Italian introduction of Sambursky's book:

> Ci limitiamo ad esprimere i nostri dubbi sull'imperativo, che il Nostro sembra voler ricavare dalla constatazione anzidetta: imperativo che tende a precludere allo scienziato ogni contatto con la filosofia. Sarebbe facile opporgli che questi contatti si sono, proprio nel nostro secolo, rivelati fecondissimi nell'ambito della matematica pura [...], in quello della fisico-matematica, ecc. Ma sarà meglio limitarci ad un argomento *ad personam*, osservandogli che egli stesso dimostra praticamente l'impossibilità di tale assoluta separazione: proprio la sua indagine, infatti, risulta pervasa, da cima a fondo, di un appassionato spirito filosofico. Geymonat, *Prefazione*, in Sambursky Italian translation (1956), p. 15.

What one may add is on the contrary a clear demarcation between the principles of science and the principles of philosophy. As Oppenheimer for instance puts in evidence a "perpetual doubting and a perpetual questioning of the truth of what we have learned is not the temper of science" (cit. p. 24), while in the philosophical perspective a *critical* habit is the principal standpoint (Oppenheimer, 1954/1955).

> If Einstein was led to ask not "What is a clock", but "How, over great distances and with great precision, do we synchronize clocks?" that is not an illustration of the skepticism of science; it exemplifies rather the creative reasoning creating a new synthesis from paradoxes, anomalies, and bewilderments, which experiments carried on with new precision and in a new context brought into being. All this means that science is cumulative in a quite special sense. Oppenheimer (1954), p. 24.

Here one should remark the different use of the term "critical". While in the Kantian approach of philosophy the term is used to refer to a perspective that necessarily puts into light the limits of human reasoning and cognition, thus doing exactly what Oppenheimer was saying it proposes an "perpetual doubting" which is contrary to science habits, science critical thought is an active one, synthetic, which creates new forms and structures by means of a synthesis from paradoxes and anomalies. One may add that the constraints of a critical perspective in both meanings and in both domains is of help in every thought in general[29].

7.

> In the course of our century, physics has made some extraordinary advances, coming to a comprehensive understanding of fields that had been till nowadays beyond human reach and has applied its leading principles with an incredible success. Although these spectacular results – or rather because of them -, the pivotal concepts that underpin the entire science structure seem to disregard all main efforts maid to attain a definitive clarification. Jammer (1971)[30].

This is a quotation from the famous book *Concepts of Force: A Study in the Foundations of Dynamics* made in 1957 by Max Jammer. He has dedicated a special part of his research elaborating a conceptual history of some of the main notions in physics and philosophical thought, such as space, force and mass[31]. As well known, every concept that has reached its scientific status is traditionally given for granted, nevertheless it hides another peculiar history.

We can delineate two different aspects: on one side a conventional-traditional use, which habitually comes from practices and applications and seems immediately accessible and on the other side a more implicit use, which instead needs to be questioned. One should put into light that this *implicit reference* to terms and concepts does not happen only in

---

[29] On this argument see (Chalmers 1976).

[30] "Nel corso del nostro secolo la scienza fisica ha compiuto grandi progressi, pervenendo a una conoscenza approfondita di campi fino ad oggi inaccessibili all'uomo e applicando i suoi princìpi fondamentali con successo senza precedenti. Ma nonostante questi risultati spettacolari – o forse proprio a causa di questi –, i concetti-cardine che soggiacciono all'intera struttura della scienza sembrano sfidare più che mai tutti gli sforzi fatti per giungere a una chiarificazione definitiva". "Prefazione all'edizione italiana del 1971", op. cit., English translation is ours.

[31] *Concepts of Space: The History of Theories of Space in Physics*. Cambridge (Mass): Harvard University Press, 1954; New York: Harper, 1960; 2nd ed: Cambridge: Harvard U.P., 1969; 3rd ed: New York: Dover, 1993. (Foreword by Albert Einstein). *Concepts of Force: A Study in the Foundations of Dynamics*. Cambridge (Mass): Harvard U.P., 1957 New York: Harper, 1962 New York: Dover, 1999. *Concepts of Mass in Classical and Modern Physics*. Cambridge (Mass): Harvard U.P., 1961 New York: Harper, 1964 New York: Dover, 1997.

ordinary language, but also and characteristic way in science[32].
Oppenheimer helps us in adding also another element to this argument. In a collection of texts *The open mind. Science and the common understanding* (Simon and Schuster, N.Y., 1954/1955) talking about the relation between theoretical and practical aspects of experimentation and technical devises in the mind of a scientist says that:

> The notion of how it is supposed to perform is for him in general a fixed thing not calling for further inquiry. This may be true even when the invention is a sample of practical art rather than a sample of true understanding. The photography plate has served as an instrument of science for decades, during which its behavior was only very incompletely understood [...] Nevertheless we use what we have learned to go further. A perpetual doubting and a perpetual questioning of the truth of what we have learned is not the temper of science. Oppenheimer (1954/1955), p. 24.

Here we see in Oppenheimer words in the fifties a profound description of human and thus scientific habit, which is the result of a stratification and which in its evolutionary aspect do not interrogate about already costumed things.
Jammer puts in evidence a significant consequence to this fact. The established habit of the classic employment of a term is one of the reasons for a *neglect* of the more problematic nature of the concept. And the more troublesome thing is that this habit is scarcely take into account in science discussions. This neglect may happen in two directions. One that prevent the recognition of an implicit employment of a concept in a most problematic way, as for instance we are trying to put into light with this work33, and another which conversely prefers to see emerging paradoxes from the connection between statements expressed in ordinary

---

[32] See also the fine analysis on metaphors the text already mentioned by Black, Hesse, and the epistemological critical tradition started with Canguilhem, see note...and 34; for a commentary on science et ideology according to Canhguilhem see also Debru (2004). The eminent study on ordinary language hidden mechanisms is still Wittgenstein's *Philosophische Untersuchungen*. For a discussion on the role on metaphors especially in life science see (e.g. Galiasso, Frezza, 2010).
[33] See also the analysis of the metaphor of the mirror used in mirror neurons experiments (Frezza, 2009).

language than taking into account a proper discussion about their specific theoretical background (Bitbol, 2008; Longo, Frezza, 2010).

A second element that we learn from Max Jammer, which adds something to Feynman's quotation above about the need of approximation in physics, is that in every research concerning a concept comes up a difficulty from the primary *implicit indefiniteness of its definition*. The scientific pragmatic attitude that faces this vagueness is the determination of the concept in one exact definition. But the result of this operation is often necessarily a delimitation to more recent operative criteria that do not contemplate the ancient history of the concept[34]. This leads to a "hidden zone" of the research that is not explicit and cannot be looked through directly, but which is full of fertile developments for the thought[35]. As we have hint in ex-ergo with Bitbol's words one should start to strip off the interplaying between concepts of this hidden zone and try to dissociate their major threads.

Another consequence of this scientific clarification-delimitation procedure about terms and concepts is the establishment of the definition in a specific context of application, thus in distinct domains and normally in different epochs. This inevitably creates a dynamics in continuous evolution, as the context is constantly changing through science times. Jammer therefore proposes that the determination of the development of a concept should be necessarily opened. Knowing that one needs to cope with the risk of putting to the definition of the concept too vague boundaries or too rigid ones.

We should keep in mind this definition process for our (hi)story about the concept of interaction. In fact along our way we have already noticed the possibility of different references to this notion: one that is the common applicative use which is more recent and very diffused (see introduction) and another that comes through the analysis of its (hi)-story, thus it has an historical, more hidden and implicit character. Trying to explicit our methodology we should say that to grant a better

---

[34] See the work of Benveniste (1969) about the linguistic occidental dictionary.

[35] See the great work of Canguilhem about the notion of reflex (1955) and (Debru, 2004) for Canguilhem's critical work on science and ideology; a classic is also Foucault's work on society and episteme (1966) (1972);

clarification and understanding of the concept of interaction we move along two directions at the same time. One hand we expect to find some elucidations tracking back the various applications of the notion in their specific and characteristic fields, as we are doing for physics. On the other hand, we follow Jammer's suggestion that seems to apply very well to the polarity of the concept of interaction: whichever definition we may find, in the end we should nonetheless hold supple boundaries!

8.

We have learned that "fundamental interactions" are earth basal interactions. Said like this one may have the impression of a tautology and think that it was quite evident in itself without any analysis. But then one should add, "All the known forces of nature can be traced to these fundamental interactions"; by which we gain a relation between the notion of force and that of interaction. We also know that in physics both notions entail the concept of particle and that we have four criteria to organize and define these interactions:

- the types of particles that experience the force
- the relative strength of the force
- the range over which the force is effective
- the nature of the particles that mediate the force

These are all distinguishing and measurement criteria. To understand something more in the direction of our epistemological analysis we have tried to look also at the ancient definition of the atom. The ancient descriptions of the atom have put in evidence the importance of the criteria of number, identity, causality, movement, aggregation and also randomness, emergence and plurality. We have noticed that despite the traditional consideration of a mechanical cinematic theory of atoms, one may find represented in it at the same time some traits of emergence and a distinction in different levels of phenomenality.

Having collected these elements, now we may need to look directly at the interplay between force, interaction and particles in more recent physical descriptions. As Feynman explains (2006), the configuration of the physical world before 1920 had for stage the three-dimensional space of geometry delineated by Euclid, and as actors, the particles, which were changing in a medium called time. These elements on the stage such as particles or atoms had some properties[36] such as inertia, by which if a particle is moving it keeps on going the same direction unless a force acts upon it (if the resultant force is zero, then the velocity of the object is constant)[37]. Moreover forces were divided into two big categories:

> First, an enormously complicated, detailed kind of interaction force which held the various atoms in different combinations in a complicated way, which determined whether salt would dissolve faster or slower when we raise the temperature. The other force was known was a long-range interaction - a smooth and quiet attraction - which varied inversely as the square of the distance, and was called *gravitation*. Feynman, 1956, 2-4.

The kind of short-range forces were firstly seen at work in the "chemistry machinery". In the interaction between carbon and oxygen, for instance, carbon attracts only one or two oxygen atoms but not three. One may imagine a sort of gravitational force but enormously more powerful and with a substantial difference. While in the *world of gravitation* everything attracts everything else, according to this different interaction, called electrical, one should imagine a world of *two* principal things: the *charges*. These have the property that only unlikes *attract*, while likes *repel*. In this *polarized world* we have a stable situation where two charges, namely a plus and a minus, are closed together attracting each other; if we introduce another charge at a

---

[36] See the discussion about particle properties in new quantum mechanics Bitbol (2008), op. cit.

[37] A consequence of Newton's first law (1687): "Corpus omne perseverare in statu suo quiescendi vel movendi uniformiter in directum, nisi quatenus a viribus impressis cogitur statum illum mutare. (trad. "Every body persists in its state of being at rest or of moving uniformly straight forward, except insofar as it is compelled to change its state by force impressed"). In physics as motions of bodies can only be described relatively to something else, typically one refers to specific frames of reference. Inertial frame of reference or Galilean/Newtonian reference frame, for instance, expresses homogeneously time and space, isotropically and in a time independent way. In other words, Newton's law postulates that it exist at least one frame of reference relative to which the motion of a particle not subject to forces is a straight line at a constant speed. Thus, all measures in the inertial frame of reference have the property of convertibility by means of transformations: Galilean invariance or principle of relativity (1632), which was applied in Newton's physics, states that fundamental laws of physics are the same in all inertial frames; any reference frame that is in uniform motion with respect to an inertial frame is also an inertial frame. Lorentz transformation is instead used in special relativity.

distance, nothing happens. Nonetheless, the closer we get with this new charge to the other charges the more we disturb the system: attraction arises because the repulsion between the likes and the attraction of opposite charges tend to bring together unlikes and push likes far apart[38]. We may call this a “Quasi-individualistic world” or “Proto-social”, where one body meets another and starts to interact only when they are close in an intimate relationship[39]; otherwise everybody keeps its proper position. In terms of disturb, the system is stable and auto referred: nothing happens till charges get very close. Everything in this scenario seems to be *balanced* and only by accident we may instead discover the power of this *charged* electrical world, which is normally unperceived.

> All things, even ourselves, are made of fine-grained, enormously strongly *interacting* plus and minus parts, *all* neatly *balanced out*. Once in a while, by accident, we may rub off a few minuses or a few plusses (usually it's easier to rub off minuses), and in those circumstances, we find the force of electricity unbalanced, and we can see the effects of these electrical attractions. Feynman (1956), p. 2-5 (our italics).

To explain better what we called “Quasi-individualistic world”, we should introduce a nuance. We said simply that two charges attract each other, while it would be more correct to say that the presence of a positive (or negative) charge disturbs or *creates a condition in space for* the negative (or positive) charge to feel the force acting and reacting. This *potentiality* of charges for being excited or being perturbable by a force is called “electric field”[40]. There are two simple rules in this world:

- stationary charges make a field

---

[38] In the example of two little balls charged positively, they repel each other as their charges are of the same sign. The repulsion is described by Coulomb’s law (1783), a law similar to Newton’s gravitational law: "The magnitude of the Electrostatics force of interaction between two point charges is directly proportional to the scalar multiplication of the magnitudes of charges and inversely proportional to the square of the distances between them." For a fine history of the development of the notion of charge see Oppenheimer (1954/1955), in particular the text on “Rutherford”.

[39] There are three individual space categorizations: long distance, peri distance and intimate, see Rizzolatti, Sinigaglia, 2006.

[40] The electromagnetic field can be seen as the combination of an electrical field with a magnetic field; moving charges’ interaction is described by Maxwell’s equations and Lorentz force law. Electromagnetic field is considered as a continuum; from a quantum field theory standpoint instead the field becomes quantized. For an extended critic on Einstein reasoning on field see Balibar F., *Einstein 1905. De l’ehter aux quanta*, PUF, Paris, 1992, especially part III.

- charges in the field bear forces on them and consequently move (currents).

Here it is the nuance: the field introduces a sort of "extended friendship pact" and makes this individualistic world a little less intimate or in other terms more contextual, reciprocal and communicative. In fact, although the forces between two stationary charges should decay proportionally to the inverse of the square of the distance as we said, we observe that when we shake a charge, its influence extends very much farther out with respect to what we would have imagined.

Feynman makes an analogy with two floating corks in a pool of water (Feynman, 1956). Looking only at the two corks, when one pushes the water with one cork, one would see that one cork is directly moved in reaction of the other moving: in a correspondent *interaction between them*. If now, we consider more attentively the situation, we understand that in reality we have perturbed the water in which the two corks were immersed. Rather than assuming a *direct causal interaction* between the corks, we should assume a *non-direct interaction* among various agents and among agents and their context. The same water that we have perturbed moving the cork consequently disturbs the other cork immersed in it. In the perturbation a new phenomenon has arisen:

> There is an influence *very much farther out*, an oscillatory influence, that cannot be understood from the *direct interaction*. Therefore the idea of direct interaction must be replaced with the existence of the water, or the electrical case, with what we call the electromagnetic field. Feynman (1956), p. 2-6.

It is interesting to underline that *no direct interaction* is at work. From what we have learned, the correlation between force, particles and interaction should not be considered in a direct way. To explain the situation described above one should bring in the notion of field, which introduces a *potentiality of interaction* rather than a *direct* interaction. This element of potentiality that we start to see here is not just a nuance and is something of which we will see its increasing relevancy further on. Just as a hint: passing from the idea of *action* and force to that of *interaction* it the *potentiality* in the relationship becomes fundamental for the explanation of the phenomena.

This was Feynman's description of the physical world before 1920. We can recall some characteristics:

6. the "stage" is the three-dimensional space of geometry by Euclid
7. things stands and evolve in a medium called time
8. the elements on the stage are particles, for instance atoms, which have some properties such as inertia.

As we know going on something has changed in the vision of this world. Here we can only hint how Einstein's general relativity theory (1915) modified the stage from a three-dimensional Euclidean space to a space-time shaped by gravitational forces[41]. In our discussion we are not concerned in discussing Einstein's theory, but rather in following the development of the notions of force, particle and interaction that we have seen described till the 1920s[42]. In the "new world" of quantum mechanics, Newton's mechanical laws of inertia and force are no more valid and even the notion of particle has been under attack requiring a change of paradigm. The most peculiar change concerns the scale of observation. In fact in quantum mechanics' standpoint one discovers that things no longer appear and behave in the same way, rather they behave differently with regards to the scale of observation[43]. We have already seen this main theme of different level of phenomenality concerning ancient Atomist theory. Regards the notion of particle, as we will see later in detail, it has been discovered that at high frequencies the electromagnetic waves carried by the electric field can behave more like particles than like waves. Quantum mechanics began to explain this behavior unifying the idea of particle, the idea of the field and its waves.

---

[41] Einstein two steps theory of relativity: special (1905) and general. General relativity generalizes special relativity and Newton's law of universal gravitation, providing a unified description of gravity as a geometric property of space and time, or spacetime. For a general outlook see *The principle of relativity: a collection of original memoirs on the special and general theory of relativity*, (eds.) Lorentz H.A., Einstein A., Minkowski H., Weyl H., Dover, N.Y., 1952.

[42] In Einstein's Relativity Newton's mechanics becomes a case limit, and in a sense the law of inertia still defines the motion of a free particle, in general relativity this is valid also for a particle in gravitational field because anyhow it is free.

[43] For a discussion of a modal interpretation of Q.M. in terms of relational properties see, Berkowitz J., Hemmo M., "A new modal interpretation of Q.M. in terms of relational properties", *Physical theory and its interpretation. Essays in honor of Jeffrey Bub*, (eds.), Demopoulos W., Pitowsky I., Springer, Dordrecht, 2006, pp. 1-29.

Thus we have a new view of electromagnetic *interaction*. We have a new kind of *particle* to add to the electron, the proton and the neutron: the photon.

> The new view of the interaction of electrons and protons that is electromagnetic theory, but with everything with quantum-mechanically correct, is called quantum electrodynamics. Feynman (1956), p. 2-10.

Moreover in the 1920s-1930s Rutherford's (and then just before World War II, Chadwick's and Hahn's) collision experiments on alpha particle and radioactivity families (uranium and thorium) helped to discover several new particles.

> Even this was only the beginning. In the very energetic particles of cosmic radiation, in the nuclei accelerated by giant modern accelerators to energies a hundredfold those of Rutherford's alpha –particles, we have found new probes to elicit new phenomena; the story of sub-nuclear matter began to unfold and ramify. A whole new family of hitherto unknown, and, for the most part, unrecognized and unexpected objects began to emerge from the nuclear encounters. [...] In the last years there have appeared in increasing variety objects heavier than protons, whose names are still being changed, from month to month, by solemn conferences. Oppenheimer (1954/1955), p. 32.

The picture emerging from this revolution is a world dominated by several particles rather than three[44]. As large as it may be this number – because in the 50s there were knew something like thirty elementary particles and many more have been found through artificial collisions[45]– nonetheless their interactions are not completely different. They are traceable, in a decreasing order of strength, in these four:

- nuclear interaction

[44] For a keen commentary on this revolution and particularly about the typical character emerging from these investigations by which the object of study becomes an instrument of further analysis see Oppenheimer (1954/1955), op. cit, especially pages 129-155.

[45] By now in the standard model the number of elementary particles are: 6 quark, 3 leptons, 3 neutrinos, foton, W+, W-, Z0, gluon, higgs.

- electromagnetical interaction
- weak interaction or beta-decay interaction[46]
- gravity

Nuclear force, also known as “nucleon-nucleon interaction” or “residual strong force” is the force between nucleons. It specifically binds protons and neutrons. There have been different explanations of it since 1934 when it was firstly discovered, shortly after the discovery of the neutron by Chadwick in 1932 and the detection of the force that binds proton with neutron. Nowadays nucleon-nucleon interaction is considered the residual force of the stronger force called strong interaction, which binds the particles called quarks together[47]. Electromagnetic interaction is the force that causes the interplay between electrically charged particles and which, binds the electrons to the nuclei. Weak interaction, then, which is known mostly for the nuclear beta-decay interaction, is the force in atomic nuclei by which a neutron “discharging” an electron becomes a proton (emitting also a neutrino) or the force of a neutron which beta-decays.

Finally, gravitation is the interaction responsible for the mutual attraction between objects. This, among all the four fundamental interactions, is the only force familiar to us[48], because it is the main actor that gives weight to bodies. We will analyze more in detail the parallel between the theoretical development of the gravitational force and the evolution of the concept of interaction.

It results that from Newton’s time to now the main physics concepts and the main way of thinking have changed a lot. Let us say with Oppenheimer that the principal modification in physics theory building is due to the failure of a description of Rutherford’s atom by means of

[46] One should remark that it is known since a while that weak interaction and electrical are reflection of the same force.

[47] The first particles known (1947) to conduct the nuclear force, the mesons, were themselves understood in the 1970’s to be combinations of quarks and gluons, transmitted between nucleons that were made of quarks and gluons themselves. This conception allowed the strong forces that held nucleons together to be felt in neighboring nucleons as residual strong forces. Nuclear forces arising between nucleons are nowadays considered analogous to the forces in chemistry between neutral atoms called van der Waals forces.

[48] A very interesting commentary suggested by a friend physicist is that nonetheless the force that we feel when touching the wall with a finger (which determines the non-penetrability of solid bodies) is the electromagnetic interaction.

Newton's mechanics, which leads to the problems of a unique physical theory that I will comment further on.

> The atoms of nature are radically, dramatically, unlike atoms, composed as Rutherford found of electrons and small nuclei, subject to these forces Rutherford discovered and described, and moving according to Newton's laws. The failure of this classical description turned out to be a major clue, one of the major clues, in the atomic story. [...] more than Newtonian mechanics would have to be modified if we were to understand and describe our experience with atomic systems. We would have to alter our ideas on very fundamental points, on causality, for instance, and even on the nature of the objectivity of parts of the physical world. Oppenheimer (1954/55), p.33-34.

Nonetheless, as we have seen, from last centuries discoveries to nowadays fundamental interactions are still the same and also the main questions in particle physics, that is still an open field of research especially prolific in CERN's experimentations, the world's largest particle physics laboratory[49]. But what made possible the new look on physical matters?
I want to put into light this very utile point for our research with Oppenheimer's words.

> Many new ideas and methods of description were to be introduced. We learned words new for us, like "quantum", and "state", words like "correspondence" and "complementarity", words with a new meaning for physics. Of these the word "correspondence" came to stand for the conservative and traditional traits of the new physics, that bound it to the physics of the past; whereas "complementarity" described, as we shall come to see, those new feature, unknown to the physics of Newton, that have broadened and humanized our whole understanding of the natural world. Oppenheimer (1954/55), p.34.

This text is quite a revelation for our questioning on the concept of interaction. My idea of an intrinsic polarity in the concept between a deterministic and a multi factorial characterization, as well as the contra-position in the notion of atom between strictly mechanical laws and the consideration of emergence properties, seem to be condensed all here in

[49] Cern, European Organization for Nuclear Research, http://www.cern.ch

this description. We recognize a traditional approach to interaction which is represented especially by the equality with the Newtonian concept of force and that is resumed by Oppenheimer in the text above with the term “correspondence”, putting into light in particular the reductionist-connexionist approach of reducing a theory to another[50]. While one underlines another approach, that contravenes Newton’s principles, which focuses particularly on multi-factorial experiences and that is described by Oppenheimer in the quotation above under the notion of “complementarity” which we will widely discuss in next section.
I want to elucidate another element, which I find very interesting. Oppenheimer regards to this second approach, the complementarity one, as a tendency that has *humanized* physical research and our conception of the natural world. How should we interpreter this humanizing trait? How does the principle of correspondence oppose to that of complementarity? And is there a relation between the conditions put into light by complementarity principle, the reductionist expectation of the correspondence principle and the possible “humanization” of physics? I think that the (hi)story of the concept of interaction that I am trying to delineate may be a key for the analysis of this humanization of physics: crossing the borders of disciplines and researchers’ activities, making evident the interaction aspects of our world and of our understanding of it and developing also the possibility of these same interactions. We should add that this approach is intended in the critical perspective that we have mentioned or in a complementarity one: both against a totalizing final-finalist description of the world as we are at length going to see in

[50]The "correspondence principle" formulated by Bohr in 1920 (Bohr, N. (1920), "Über die Serienspektra der Element", Zeitschrift für Physik 2 (5): 423–478) firstly introduced for a correspondence between classical physics and quantum mechanics is generally used to mean the process of reduction of a new scientific theory to an earlier scientific theory. This process requires that the new theory explains all the phenomena under circumstances for which the preceding theory was known to be valid, delineating the "correspondence limit": in order for there to be a correspondence, the earlier theory has to have a domain of validity—it must work under some conditions. As known not all theories have a domain of validity. See Chalmers (1976) for a discussion of the problem of uncertainty for theorizing the validity of science in general. The problem of a descendant-ascendant continuity of quantum mechanics with measure instruments and ordinary world is analyzed by Bitbol (2008), especially in the direction of quantum mechanics instrumentalist standpoint versus a theoretical approach directly based on procedural practice.

next section[51].

9.

We can resume briefly that in physics force and interaction are technically used as synonyms when referring to fundamental interactions. We should remark, though, that while the word force was central in the physic of Newton's time, nowadays the notion of *interaction* is more precisely used when we want to refer to the notion of field and more specifically also to nuclear forces. As we said, when one comes into microscopic world Newton's laws are no more valid and correspondingly the concept of force that was central in classical theories needs to be differently specified in a quantum mechanics reference.

> In nuclear analysis we no longer think in terms of forces, and in fact we can replace the force concept with a concept of *energy of interaction of two particles*. Feynman (1956), p. 12-17.

In the book *Physic and philosophy* Heisenberg explains some of the great philosophical changing introduced with quantum mechanics. We will especially make reference to this text, which contains at the same time an analysis of Bohr's complementarity principle and its theoretical consequences. For other aspects concerning more recent philosophical questioning about quantum mechanics revolution we will mention also the book by Michel Bitbol, *Mecanique quantique. Une introduction philosophique* (2008).

We start by briefly resuming some of the main traits of this theoretic revolution which are of special interest for our discussion, putting into light after our first analysis of the notions of force, field and particle,

[51] For a description of this problem in physics see Demopoulos W., "On the notion of a physical theory of an incompletely knowable domain", in (eds by) Demopoulos W., Pitowsky I., 2006, Op. Cit, pp.101-116.

the *second aspect* of the conceptual family of the concept of interaction, that of complementarity, interference and polarity.

> I remember discussion with Bohr which went through many hours till very late at night and ended almost in despair; and when at the end of the discussion I went alone for a walk in the neighboring park I repeated to myself again and again the question. Can nature possibly be as absurd as it seemed to us in these atomic experiments? Heisenberg (1958),p. 42.

As we hinted above, de Broglie proposition (1924) of the particle-wave duality stated that a certain wave corresponds to an electron moving as well as a wave of light corresponds to a quantum light moving, even if in this description the precise meaning of the term "corresponding" was not clear. Afterward there have been two different developments for reaching the precise mathematical formulation of quantum theory. One that follows de Broglie's idea and which was developed by Schrödinger, which argued an undulatory equation for de Broglie's stationary waves around nucleus and the other direction pointed out in Bohr's correspondence principle. Following the idea that one could firstly study electronic big orbits and then try to apply these results also to little orbits, it was established that rather than mechanical laws on electrons positions and velocity equations one should develop frequency and amplitude equations of electrons Fourier expansion52. In 1925 this project was developed in a mathematical formalism called matrix mechanical or quantum mechanics, leading to the substitution of Newtonian mechanical equations of motion with new similar equations between matrices. Later one exception was discovered: matrices expressing momentum and electron position are not commutable, clarifying the fundamental difference between quantum and classical mechanics.

The other approach was followed by Schrödinger, who by means of a series of studies established not only that wave mechanics entailed quantum mechanics, but also that it was possible a mathematical equivalence between the two theories, expressing a relation in two

[52] Radiation deriving from big orbits by means of frequency and intensity gives an image of the electric orbit, represented by the so called Fourier expansion of the orbit.

directions, between matrices or undulatory equations53. In the same year Born gave to this mathematical equivalence also a physical description and, later on, Dirac transformations theory showed how one might express quantum mechanic and quantum wave mechanics by means of a same scheme. As Bitbol (2008) puts in evidence the problem was that this common scheme was purely formal and could not be associated to a powerful vocabulary that would have granted also a common element of denomination54. In spite of the fact that Schrödinger was able to find a mathematical formalism apt to equalize quantum mechanic formalism with undulatory one, nonetheless the paradoxes of the dualism between the two descriptions, corpuscular and electromagnetic, rested behind the mathematical calculus (Heisenberg, 1958).

These two became the stigmatizing characters of the new physics and have been interpreted typically as an "ineluctable" polarity of the physical description of the microscopic world. For instance when we physically talk in terms of corpuscle, referring to a limited *substance* in a *little* volume, we cannot make reference at the same time to the notion of wave, such as the *field* that propagates in an *open* space. This consideration of a specific complementarity lead to the "celèbre querelle" wave-particle in the physics of those years55.

> Les deux formes initiales de la mechanique quantique n'ayant jamais ete' clairement subsumees jusque-la sous un meme concept, le conflit dont elles furent le motif en 1926 s'est longtemps prolonge' sous une forme latente. Sa trace est reste' lisible dans un accident de denomination. Tandis que le groupes de de Broglie et Schrodinger appellaient la nouvelle theorie "mechanique ondulatoire", privilegiant ainsi la representation continue et les effets d'interference, le groupe des physiciens de Gottingen et Copenhague (Heisenberg, Born, Jordan, Pauli,

[53] This result known as Schrödinger equation, was formulated in 1926 "Quantization as an *Eigenvalue* Problem", *Annalen der Physik*, which describes how the quantum state of a physical system or wave function changes through time. One should remark that this function is a pure mathematical entity that, by means of a probabilistic interpretation, without the support of any physical element from a determined space gives all the possible states of the system into the complex numbers.

[54] For the solution that Bitbol (2008) proposes of this argument in terms of the "predictive contextual formalism", see all chapter II and particularly pages, 224-234.

[55] As Bitbol remarks, this dispute for some traits requires an analysis of the special denomination characters while for others puts into light some incongruences at the level of an extrapolation of the images used as explanation out of their proper paradigm (Bitbol, 2008).

> et aussi Bohr a’ la suite des premiers) la qualificaient de “mechanique quantique”, ce qui revenait a’ generaliser l’un des noms donne’ a leur version de la theorie et a’ privilegier par la’ la representation discontinue et les effets de quantification. Bitbol (2008), p. 224.

“But what’s in a name?” As Bitbol enlightens, the quantum aspect became prevalent and more diffused, preventing the more complex idea of this entire revolution to be spread out. We notice –and we will see also later on talking about Sonnenschein-Soto’s argument about cellular proliferating default state– that under a “dispute between names” one finds much more than a barely nominative aspect: the fight for a name may mark an entire culture. For instance see the informational metaphor of DNA as a genetic programming code that has signed the biology debates for nearly 70 years (Fox-Keller, 2000) becoming such as the emblematic Montecchi vs. Capuleti fight in Shakespeare tragedy. And again we should remark that this process happens in ordinary as well as in scientific practices, once again the permeation of our epistemological culture into science matters is evident.

The “final solution”, as Heisenberg calls it, has been approximated by two different paths (1958, p. 42). The first approach replaced the question “How can we express in known mathematical terms a certain experimental situation?” with the question “Is it true that in nature can occur only experimental situation as such to be expressed in the terms of mathematical formalism?”. In this way one has discovered some *limits* in the use of physical classical notions, leading to what is known as the “uncertainty principle” (1927). One may talk about the position and the velocity of an electron, observing and measuring these quantities, as well as one may do in classical mechanics, but it is impossible to determine *at the same* time these quantities with any great degree of accuracy or certainty. This fact showed that classical concepts adapt to nature only approximately.

The second approach was concerted in Bohr’s complementarity principle. Here we are especially interested in some traits of this “complementarity” revolution. Bohr refers to it in many and different meanings[56]. In the most general terms the emergence of complementarity in a system occurs when one considers the circumstances under which one attempts to measure its properties; as Bohr noted, the principle of complementarity implies the impossibility of any sharp separation between the behavior of atomic objects and the interaction with the measuring instruments which serve to define the conditions under which the phenomena appear. We may underline five main references, in our non-technical and simplified terms.

First of all with complementarity (1) Bohr refers to the fact that the two images, corpuscular and undulatory are two complementary description of the same reality.

> Any of these descriptions can only be partially true, there must be limitations to the use of particle concept as well as of the wave concept, else one could not avoid contradictions. If one takes into account those limitations which can be expressed by the uncertainty relations, the contradictions disappear. Heisenberg, (1958), p. 43.

This combined element brought to the so-called "Copenhagen interpretation of quantum mechanics" (1927), which was finally established in Solvay conference in Bruxelles. As Heisenberg clearly underlines this interpretation was made on the basis of a paradox: classical physics terms are those proper to describe experiments, nonetheless the application of these concepts is delimited by the *uncertainty relations*.

According to Heisenberg, Bohr used also another determination of complementarity which is far close to the uncertainty principle (2) by which one may refer to the fact that the knowledge of the position of a particle is complementary to that of its velocity or its momentum (Heisenberg, 1958, p. 64)57. The closer we get to one measure the farther

[56] Bohr N.,*Causality and complementarity: epistemological lessons of studies in atomic physics,* Ox Bow Press, 1999, and *Niels Bohr Collected Works*, "Complementarity Beyond Physics (1928-1962)", Volume 10, (ed. by) Aserud F., Niels Bohr Archive, Copenhagen, 2008.

[57] For a study on Heisenberg and Bohr principles see: Delbruck M. (1944), *Problems of Modern Biology in Relation to Atomic Physics*, Vanderbilt University School of Medicine Library; Pattee H.H. (2001),"The physics of symbols: bridging the epistemic cut, *Biosystems*, 60,1-3, pp.5-21; Domondon A. T. (2006), "Bringing physics to bear on the phenomenon of life: the divergent positions of Bohr, Delbrück, and Schrödinger, Studies

we get onto the other. Nonetheless, to have an approximately precise comprehension of the system one should effectuate *both* measurements. There are two main characteristics then: the spatial-temporal description of atomic events results complementary to their deterministic description via the equations of the function of probability. One might look more attentively to this explanation:

> The probability function obeys an equation of motion as the co-ordinates did in Newtonian mechanics; its changes in the course of time is completely determined by the quantum mechanical equation, but it does not allow a description in space *and* time. Heisenberg, (1958), p. 49.

This means also another complementarity (3): the observation, thus the measurement, grants the spatial-temporal description, but at the same time it introduces a break in the determined continuity of the function of probability expressed by the quantum mechanics equation, modifying our knowledge of the system. Again, this complementarity aspect altogether in all these different aspects keeps our knowledge of the system in a continuously modifying state. In other words, we cannot obtain an objective result of a measurement of the entire system.

Thus we may underline another complementarity (4): either we accept our approximate character of knowledge or we attribute this uncertainty to our world. The technical warrant of this troublesome uncertain and dualistic (undulatory and corpuscular) description of the matter is, as we have seen, the mathematical formulation of a non-contradictory theory that allows writing and transcribing a corpuscular equation in terms of quantum mechanics; yet it is a *theoretic* counterpart of the pointed out ambiguity of the matter. The interpretation of electromagnetic waves in terms of probability rather than reality (Bohr, Kramers and Slater) brought to the idea that it was not necessary that energy and momentum conservation laws would be true for the single event because they were only statistic laws, thus true in the meaning of a statistic mean. Even if this conclusion was not exact, it allowed clarifying an essential trait of quantum theory. The concept of probability in statistic expresses an

---

in History and Philosophy of Science Part C, 37, 3, pp. 433-458.

affirmation about our grade of knowledge of the effective situation. Wave probability ads something more, a “tendency towards something” entailing completely a new way of thinking from classical mechanics.

> It was a quantitative version of the old concept of “potentia” in Aristotelian philosophy. It introduced something standing in the middle between the idea of an event and the actual event, a strange kind of physical reality just in the middle between possibility and reality. Heisenberg, (1958), p. 41[58].

One should explain this paradox of a physical phenomenon in between of a reality and a possibility by the fact that the function of probability represents the experimental situation in the moment of the measurement, including also the possible errors. This function expresses two things at the same time: a fact and our knowledge about it. In other terms it gives the unity of probability (certitude) to the initial condition: the electron moving with the observed velocity in the observed position (in the limits of the experimental conditions). But at the same time another observer could possibly describe the same conditions with a more precise grade of definition. This means that the error calculated in the function of probability is not to be ascribed to the electron, but to our deficiency in getting its trajectory. This means also that the function of probability that from these initial conditions calculates the probability for another further time, at the same time *does not represent* in itself the *real course* of the events *that is happening* along different times; as we said before rather a tendency of the events, which is always present.

> The probability function can be connected with reality only if one essential condition is fulfilled: if a new measurement is made to determine a certain property of the system. (Ivi, p. 46).

In this way Heisenberg distinguishes the theoretical interpretation of an experiment in three different stages:

- The translation of the initial experimental situation into a probability function.

[58] For a general philosophical description of the notion of randomness see Conche M. *L'aléatoire*, Editions de Mégare, 1989, Paris.

- Following this function through time.
- The determination of a new measure of the system the result of which could then be calculated by the function of probability.

He adds that the uncertainty relations are condition for step one and that the fact that step two cannot be calculated in classical terms entails that there is no possible description of what is happening *between* initial observation and the new measurement: only in the third step we pass again from the possible (function) to real (new measurement).

The transcribing power of our function is limited: determining what it is *really* happening in an atomic event creates a serious difficulty in the explication by virtue of *usual objective terms*.

> So we cannot completely objectify the result of an observation, we cannot describe what "happens" *between* this observation and the next. This looks as if we had introduced an element of subjectivism into the theory, as if we meant to say: what happens depends on our way of observing it or on the fact that we observe it. Heisenberg (1958), p. 50, our emphasis.

Here we find the last complementarity that we underline (5): it shows the polarity of the traditional opposition between objectivity, and particularly scientific one, and subjectivity. It is interesting noticing that this last complementarity points out that when one introduces a form of subjectivity is just when one lacks in objectivity. We should remark, therefore, that the occasion of de-responsibility from science objectivity introduces a sense of responsibility in terms of subjectivity. This is not just a nuance and it is something that emerged, shook and renewed the traditional classical ideas of physics; as Oppenheimer said "it humanized our whole understanding of the natural world" (cit. p. 34).

If we keep the analogy we made before talking about the "individualistic world" of classical Newtonian physics and the more "sympathetic" and opened world of electromagnetism here we are in a more "adult" world, where completely new rules reign. Keeping the analogy it is a sort of "way out" from the adolescence and becoming adult of physics. It implies the auto-analysis of what before was physics main cultural behavior; and this auto analysis initiates a new cultural behavior in its turn59. One may easily make reference here to the occasion, *kairos*, of a coincidence. The main disciplines and the philosophical tendencies of last century sometimes have enacted, sometimes reacted and sometimes firmly responded to this state of uncertainty of science, such as respectively psychology and anthropology, or phenomenology, existentialism and hermeneutics, or instead as positivism, logicism, and linguistics have differently done. It occurs a sort of "shock" for rationality talking in epistemological terms60. Anyway, this new complementarity-conscious look at the image of the world given by physics imposed a question: what does effectively happen in an atomic event?

The answer to this question in its general form may be described as the fact that the explanation of what happens during an observation is just a parenthesis juxtaposed to another parenthesis that contains the explanation of what happens during another observation and so on. Proceeding with this scheme we could easily imagine somebody who asks: but how do we know what happens in between the parentheses? On one side one may receive an answer that simply follows the scheme, getting a regression ad infinitum: we live in a world full of parentheses the consistence of which seems to vanish, but this very fact should not be contemplated. This procedure may recall the ancient principle "turtles all the way down" to explain how the world was kept up in the universe[61]. On the other side, not happy with the existence of those parentheses, we may start to search for a parenthesis of the parentheses, a general phenomenological *epoché*, or rather for a more fundamental theory of the parentheses. This very process may lead to the temptation of a metaphysic approach, intended as the quest of a foundation higher

[59] See also Bitbol (1996, *De l'interieur du monde (Essai sur la mechanique quantique)*; 2008) "Chercher l'unite' des multiples aspects ou versions du monde dans le syste'me regle' de leurs relations plutot que dans "quelque chose d'ambivalent et de neutre sous-tendant les versions' [Goodman (1978), p. 5]. Tel est le contenu que nous attribuerons en fin de parcours a' la mechanique quantique (2008), p. 13.

[60] Freud mentions three big shocks of common sense: Kepler's discoveries about the orbit of the sun, Darwin's evolutionary theory of the descent of men and Freud him-self with the discovery of the unconscious (1900). Shall we add this "quantum revolution" to the list?

[61] See Girard's parallel explanation of the essentialist approach that does not properly explains how things works, but uses a series of tautologies the truth of which is given in the beginning as a faith (Girard, 2006).

up or down in the ladder of parentheses. Either way we do not really seem to be able to unfold the world, posing the right questions, but we seem to rest in a theoretic dispute the "solution" of which depends just on how we look at the unsolvable problem: or we have a solid science that holds an unknown and always partial (and parenthesized) world or rather we have an idea of a not parenthesized whole world, and by hypothesis of a unique science, but which we know just in parentheses (or through parentheses). Which is your favorite solution?[62]

Going back to the theoretic complementarity (5) introduced above, if we focus on objectivity, we have a solid science that holds a parenthesized world, a sort of Gruyère cheese world; otherwise, if we turn our focus onto the reality of world, we lack of the solidity and of the completeness of our way to get it through science. In other words: we may obscure the lack of objectivity increasing subjectivity aspects or we may directly impose this lack of objectivity to our vision of the world. But anyhow does this sound like science activity is just putting known parentheses on our unknown world? And are we satisfied with this explanation? We leave this as a question, but in Wolpert's words:

> Both the ideas that science generates and the way in which science is carried out are entirely counter-intuitive and against common sense... Science does not fit with our natural expectation. Wolpert (1993), p. 1.

10.

> To begin with, it is important to remember that in natural science we are not interested in the universe as a whole, including ourselves, but we direct our attention to some part of the universe and make that the object of our studies. In atomic physics this part is usually a very small object, an atomic particle or a group of such particles, sometimes much larger – the size does not matter; but it is important that a large part of the universe, including ourselves, does *not* belong to the object. Heisenberg (1958), p. 52.

---

[62] For a recent outlook on science methods, main epistemological questions such as physicalism and realism approaches see Suarez M., Dorato M., Redei M. (eds by), *EPSA, Epistemology and methodology of science. Launch of the European Philosophy of science association*, Springer, Dordrecht, Heidelberg, London, New York, 2010.

Heisenberg distinguishes two sides in the "abstract" part of the experiment. A side that is purely objective, does not depend on the observer and is expressed by a function of probability the changing of which can be calculated in initial conditions. Another side concerns our understanding of the system and is subjective, as may change in relation to different observers. When in this theoretical set one encounters the experimental and measurement apparatus a difficulty appears.
Is in this circumstance that Heisenberg emphasizes the relevancy of the *interaction* with measure instruments. In fact, their influence introduces another complementarity (6), because tools are inevitably described in classical terms while the experiment is meant in quantum language. Heisenberg goes further and reminds us that there is another implicit interaction underneath:

> Since the device is connected with the rest of the world, it contains in fact the uncertainties of the microscopic structure of the whole world. These uncertainties may be called objective in so far as they are simply a consequence of the description in the terms of classical physics and do not depend on any observer. They may be called subjective in so far they refer to our incomplete knowledge of the world. Heisenberg (1958), p. 53-54.

Here also, as for the complementarity underlined above, we seem to find a typical Chinese boxes construction: when we remark one connection we straightaway discover another element that is connected with it, which in its turn is correlated to something else and so on. In Heisenberg's words, when we introduce the reference to measure instrument, we cannot prevent ourselves to perceive its connection, or better its *interfering interaction*, with the *rest of the world* or with the *context* in which the experiment is taking place. And noticing this yet again seems to request the commitment of a subject. We remark, once more, this leaning on the notion of subjectivity just when there is a lack in objectivity.
Moreover, we notice a sort of paradox between this sentence about the worldwide connectivity of the instruments of measurement with respect to the quotation in the beginning of this section where Heisenberg claimed that: "it is important that a large part of the universe, including

ourselves, does *not* belong to the object" (p. 52).

As we already had occasion to notice we should remember that past century epistemology has concerted many critics on these kinds of ideas that marginalized culture from science, subject from object etc. We will see in next section the critics to this standpoint made by the historical approach.

Anyhow it is significant that new quantum physical ideas have not passed by virtue of previous theoretical-philosophical conceptions, even if one may look at the epistemological culture that served as ground of development of these new theories (Balibar, 1992; Bitbol, 2008). In other terms and with respect to our discussion rather than ruminate whether science or philosophical thought brings theoretical changes in culture and society, one cannot exempt from considering their interaction as this work tries modestly to stress. So, for instance, we are not surprised in finding many threads of quantum mechanics' reflections in the philosophy of the time. But conversely in Heisenberg's quotation we discover a dualistic paradigm that may rather recall a traditional Cartesian dualism. This chiasm tension is interesting and we should take a time for discussing it a bit.

As we mentioned above, Sambursky (1956) proposed that for the Greeks the philosophical attitude becomes a *theoretic obstacle*: the confinement of science that created a sort of boundary to science and technique development. Casini's opinion is slightly different. He sustains that great Greeks mathematicians, but also Egyptians, Caldeians, Assyrians, did not lack of special techniques, as they were able to establish with astronomy the first example of physical-mathematics. He thinks, though, that the *barrier* was *epistemological*: the postulate that separated terrestrial phenomena from celestial ones.

> Gli uni obbedivano alla legge della circolarità, gli altri seguivano moti rettilinei o, il più delle volte irregolari o "misti". [...] L'astrologia o l'astronomia, in quanto studio delle leggi geometrico-matematiche per definizione "perfette", si sviluppò seguendo criteri radicalmente diversi da quelli della fisica terrestre, che aveva a che fare con fenomeni e moti di questo basso mondo, non riducibili in apparenza al calcolo e a figure esatte. Casini (1978), p. 12.

As we will see later in detail, Jammer has still another opinion, as he conversely sees many hints of modern ideas in the ground of Antiquity. For instance, the general hypothesis according to which natural world is regulated by astral movements is a ground for the idea of causality associated to certain distributions of objects in space that is at the base of the modern concept of force. We have already mentioned Russo's study (1997) which discovers a sort of Hellenistic scientific revolution of which we would have lost traces in reason of Middle Age teleological approach. And at last Wolpert (1993), putting the emphasis in the distinction between technique and science arrives to the conclusion that whichever enormous technological achievement was reached by ancient cultures it was not based on science, because "there is no evidence of any theorizing about the processes involved in the technology nor about the reasons why it worked" (p. 27). This statement serves to Wolpert to put into light the great distance between a *natural* practice as technique is and an *unnatural* activity such as science is, which in fact "happens only occasionally" in the history of humans, and in reason of which the origins of science in Greece take on a special significance (p. xii). Moreover according to Wolpert "Unlike science the product of technology is measured not against nature but in terms of its novelty and the value that a particular culture puts in it". We do not completely agree with this last statement because if from one hand considering the unnatural and counterintuitive aspects of science is very interesting, as Wolpert does magnificently recognizing also the pitfalls of natural ordinary thinking compared to rigorous and quantitative scientific thinking, from the other hand, we rather emphasize that every scientific culture is always permeated by an epistemological culture (Fox Keller, 2002).

Anyhow in all these examples of interdependence between thought and science we see that the influence of thought goes much more beyond the epoch of their masters. The chiasmic tension we have underlined produces a strange relationship. If new conceptions slowly pass through countries and culture they go even slower towards scientific disciplines, which have more rigorous boundaries, and in which, thus, new ideas are in condition to spread out only more tardily than in ordinary culture[63]. But it is true also the opposite direction, by which once a paradigm has been accepted in scientific community the diffusion through cultural-ordinary contexts may take a longer time.

I may therefore hint that there is a *peculiar decreasing tension* in the diffusion of new conceptions towards scientific matters: one form, which is common to ordinary culture, that is the affection for a traditional paradigm and the other which is also natural-cultural and adaptive that goes underneath theories and selects what is more convenient for the scientific community (which encounters the need of the community in Fox-Keller's words, 2002)64. Could we hypothesize that this second form, which is naturally developed, contrarily to Wolpert's opinion of science, seldom implicit and which is commonly non expressed by scientists in rigorous terms is the more difficult aspect to eradicate?65

Mecacci (1982) explains how the main philosophical reference for psychologists' researches was, and in year 1982 still was, Cartesian reflex arch, in spite of new philosophical theories and further refinement in psychology (see next section).

> La riduzione dei processi psichici a funzioni cerebrali localizzate in strutture determinate ha avuto come *costante riferimento teorico* un principio fondamentale, impiegato per spiegare il comportamento animale e umano da almeno quattro secoli e assurto a vero e proprio paradigma delle scienze del comportamento e delle neuroscienze. Si tratta chiaramente dell'arco riflesso che è stato da un lato il principio ispiratore, concettualmente esplicato o non, di gran parte della psicologia e neurofisiologia passate e contemporanee, e dall'altro oggetto in sé e per sé di riflessioni teoriche e metodologiche per un bilancio critico dei risultati e delle prospettive di queste scienze. Mecacci, Zani (1982), p.12-13.

---

[63] For an overview on epistemological-approach's studies, see Chalmers (1976) and Mecacci (1999).

[64] See also Wolpert commentary: "Associated with lay theories is a tendency to adapt and modify the theory too hastily in relation to the way people live, because people want to believe in a just and more or less ordered world over which they have some control. Many conclusions are influenced by the emotional content of the data. Bertrand Russel proposed that 'popular induction depends upon the emotional interest of the instances, not upon their number'" (Wolpert, 1993, p. 18-19).

[65] See for instance Hesse's work in the direction of a "socialization" of science, Hesse (1963); (1992); Favrin (2010).

Whith Mecacci and beyond Mecacci we may ask the reason why this concept so embedded in scientists' imaginary. We will see more in detail this point when we will come to the analysis of the concept of interaction in psychology. Nonetheless we should remark from now this established conception of a *reflection* in our process of understanding, which is explained in terms of a *direct relation*, rather than an interaction, which conversely necessarily entails polarity, interference, complementarity, approximation and an evolutionary-historical approach, in the lines of the conceptual sketch we are trying to clarify.

11.

By now we clearly see that every complementarity bring on itself an interaction-interference relationship. In the first (1) Bohr refers to the fact that the two physical images, corpuscular and undulatory, are two complementary description of the same reality. The second (2) is the interaction between the position of a particle and its velocity or its momentum, the third (3) is between measurement which grants the spatial-temporal description and which contemporary introduces a break in the determined continuity of the function of probability expressed by quantum mechanics equation; the fourth (4) is the instability of the world or of our comprehension of it; the fifth (5) characterizes previous interaction (4) as such the opposition between objectivity and subjectivity and finally there is the sixth (6) by which tools are inevitably described in classical terms while the experiment is meant in quantum language.
In all these interactions dominates the complementarity feature which entails a characteristic polarity.
This is the first time that we can *relate a precise theory on interaction*, namely physical, with our description of the *characteristic polarity* which we have found in the analysis of the concept of interaction. We clearly discern the trait of a particular relationship that giving something takes something else in return, in a complex activity of coordination,

without the possibility of one-way, linear determination. We can start to appreciate the relevancy of this idea, especially for the world of living beings, where it is a commonsense experience the fact that we do not receive anything for free, without giving something else in exchange!

Let us go back to the apparent contradiction in Heisenberg's last quotes between the scientific object, circumscribed and detached from the rest of the world ("It is important that a large part of the universe, including ourselves, does *not* belong to the object", p. 52) and its interaction with the measure instrument, which conversely is necessarily correlated to earth matters ("Since the device is connected with the rest of the world, it contains in fact the uncertainties of the microscopic structure of the whole world", p. 52-53). We may focus on this hiatus between on one side the reduction that puts into brackets the scientific object of analysis and on the other side the tenuous relation between the measurement disposal and world complexity, meant by an approximation. We recall in this discrepancy the inevitable approximation of physics of which Feynman reminded us previously.

It is interesting however that in other places Heisenberg himself remarks rather than the opposition of scientific and cultural-contextual ideas their permeation.

> It should be emphasized at this point that it has taken more than a quarter of a century to get from the first idea of the existence of energy quanta to a real understanding of the quantum theoretical laws. This indicates the great change that had to take place in the fundamental concepts concerning reality before one could understand the new situation. Heisenberg (1958), p. 43.

We underline again the decreasing process we mentioned above by which changing the fundamental concepts about reality, and thus the language to express these new notions, is the prior level to attain, in a second place, a global, rigorous, theoretical comprehension of the phenomena. Oppenheimer in the book we have already mentioned calls this process the "cumulative aspect to human life".

> The past underlies the present, qualifies and moderates it, in some ways limits it and in some ways enriches it. We understand Shakespeare better for having read Chaucer, and Milton for having read Shakespeare.[...] we see Cézanne with better eyes for having looked also at Vermeer, and understand much more in Locke for knowing Aristotle. [...] and if it is true that Job throws light on Matthew, it is also true that Matthew throws light on Job. We can understand a great deal of what is written today, knowing little explicitly of what has been written in the past. We can and do know a great deal of what Shakespeare means and intends without any knowledge of those earlier men who altered and educated his sensibility. Oppenheimer (1954/55) p. 20-21.

He although specifies that in science this resuming character is very different, and much more essential. This is in fact one of the reason, according to Oppenheimer, for the great difficulty we have in comprehending any science not being specialized in it. He quotes Hobbes, “Cosiffatta che nessuno puo’ capire che ci sia, se non chi gia’ la possegga in gran parte” (Hobbes 1904, p 55). This peculiar aspect of a stratifying knowledge in scientific culture with regards to human culture in general makes science a product that we have to examine in at least two different directions:

- The historical path that shows the relations between contemporary scientific discoveries (or concepts) and previous ones
- The utilization of earlier discoveries as an instrument of researches itself (see for instance the discovery of x ray diffraction as a way to detect DNA structure in 1953).

Another remark is that scientific products are less intelligible *in general*. Or, as Wolpert said, something unnatural and counterintuitive (Wolpert, 1993). Thus, trying to understand the diffusion of thoughts and concepts in science we necessarily have to focus more precisely onto the *reciprocal* action of science and culture.

12.

Keep following Heisenberg's argument: in the second step of the experiment, after measurement, the function of probability we have reflects the subjectivity of our incomplete knowledge and conversely the "objective" element of *potentiality*. The *result* of the observation becomes a *probability of a certain outcome* of the examination that has taken place. And differently from classical physics the function of probability does not describe one event, but a *complex of possible events*66.

Here we find another important interaction, because the observation itself makes the function changing discontinuously. In fact the concrete examination chooses among all possible events the only one that has "really" happened. I put into emphasis "really", to enlighten that we need to distinguish here many different nuances of the word "reality". In fact the function describes all (*real*)-possible events and does not preclude a priori anyone of these to happen; but the observation registers just one of them, which *becomes* or better *is*, strictly talking, the only properly *real*. We may ask then: in the opinion of a physicist are all possible events predicted by the function *real*?

Heisenberg answers negatively: "Perciò il passaggio dal "possible" al "reale" ha luogo durante l'atto di osservazione" (Heisenberg, 1958, p. 70). He is even more radical. The word "it happens", in his opinion, should be attributed only to *what happens during observation* and not in between two of them, as it should register the physical fact and not the psychological-subjective one. But, surprisingly, he continues as follows:

> And we may say that the transition from the "possible" to the "actual" takes place as soon as the interaction of the object with the measuring device, and thereby with the rest of the world, has come into play. Heisenberg (1958), p. 54-55.

We see that here comes out again the *interaction* with the rest of the world by virtue of the measure instrument. In next section we will see how Husserl describes from a phenomenological standpoint this entanglement of many levels of reality in the constitution of our

[66] See Bitbol (2008) for a comprehensive description of the logics associated to quantum mechanics, especially p. 221 and followers.

experience (Husserl, 1928; 1932). For the moment we follow Heisenberg insisting on this point:

> The measuring device deserves this name only if it is in close contact with the rest of the world, if there is *an interaction between the device and the observer*. Therefore, the uncertainty with respect to the microscopic behavior of the world will enter into the quantum-theoretical system here just as well as in the first interpretation. If the measuring device would be isolated from the rest of the world, it would be neither a measuring device nor could it be described in the terms of classical physics at all. Heisenberg (1958), p. 57 our italics.

The paradoxical character of quantum mechanics has we have already mentioned emerges in comprehending one strong opposition. On one side one makes reference to classical physics in describing the experiments made on natural phenomena and on the other one should know that this same description does not completely harmonize with their "real" nature. In part this is due to the language and the culture we dispose to theorize and make experiments that are radically based on our classical interpretation of nature.

> Our actual situation in science is such that we do use the classical concepts for the description of the experiments, and it was the problem of quantum theory to find theoretical interpretation of the experiments on this basis. Heisenberg (1958), p. 56.

We want to underline this passage. Heisenberg stresses that one cannot prevent referring to classical standards when theorizing new quantum experiments. Here we notice an interesting connection between the act of interpretation from a linguistic-philosophical approach and this re-interpretation of the laws from the physical point of view. In whichever kind of experience we find ourselves, ordinary or scientific, anyhow we are bind with our capacity of interpretation. And in the case of the two different standpoints in physical theory (classical and quantum) we are very reluctant in abandoning our "natural" approach. We necessarily remark the distance between this simple observation and all various and at length philosophical investigations that have analyzed this problem in its comprehensiveness (in particular hermeneutics researches[67]), here we just want to express the brute fact. In five words: we make what we interpret. And even what we cannot interpreter is part of our interpretation itself. Or in other terms:

> It is nevertheless useful to insist on the idea that every theoretical-mathematical structuring is a human construction: science is a construction of objectivity (as spelled out at length in Bailly and Longo, 2010)[68]. There is always a friction of the physical-biological world with the cognitive practices and representations which lead to a theory. Frezza, Longo (2010), §3.

Let us close this whole argument on complementarity and interaction with a quotation from Bohr that Heisenberg reports:

> In this way quantum theory reminds us, as Bohr has put it, of the old wisdom that when searching for harmony in life one must never forget that in the drama of existence we are ourselves both players and spectators. Heisenberg (1958), p. 58[69].

13.

Saying that a *potentiality* becomes susceptible of an *objective* knowledge is undoubtedly a revolution. We cannot remain and go through this question pervasively and in its wide spectrum from physics to philosophy, nonetheless we need to put into light some of its main elements because they show a fundamental twist in the (hi)story of the concept of interaction that we are analyzing. In this sense the book by Claude Debru *Le possible et les biotechnologies* (2003) which discusses the possible in the history of thought, biology and nowadays

[67] For instance from Heidegger's remarks in paragraph 17 of *Sein und Zeit* to Gadamer's theory of interpretation as a game (Gadamer, *Wahrheit und Methode. Grundzüge einer philosophischen Hermeneutik,* 1960; *Truth and Method*, 1989), Ricoeur P. (1969), Le conflit des interprétations, Essais d'herméneutique I, Le Seuil, Paris.

[68] Bailly F., Longo G. (2010), *Mathematics and natural sciences. The physical singularity of Life*, Imperial College Press/World Sci. (preliminary version, in French, Hermann, Paris, 2006).

[69] See Bitbol (2008, p. 219).

biotechnologies may help us. Debru analyzes the influence and the development of the concept of the possible in a "semantic of the possible", from Greeks to nowadays biotechnologies. We underline with him the powerfulness of this concept and, particularly, its importance in biological sciences, that treats contingents events as living being are, as we will discuss in next section. "Il s'agit toujour d'expliquer le monde visible par des forces invisibles, d'articuler ce qu'on observe sur ce qu'on imagine" (Jacob F., 1981, *Le jeu des possibles*, Fayard, Paris, p. 27).

> L'univers biologique est caracterisé par l'espèce particulière de nécessité (necessité conditionelle) propre aux choses contingentes. Il s'est construit, d'une maniere qui est loin d'etre entierement claire, comme un ensemble d'etres complexes qui entretiennent entre eux et avec le milieu physique des interactions nombreuses. Pour le decrire la science d'aujour'hui utilise plutot le langage de la complexite'". Debru (2003), p. 97.

If we pass in examine some of the most eminent examples of the meaning of "possibility" in the history of occidental thought (Debru, 2003), we shall argue that it is not trivial that potentiality is truly something or would participate to proper real events category. For instance in Parmenides' reflections on being and not being, or the Modern Age dispute about gravitational action at distance at Newton times, in both occurrences the possible is observed much more in the sense of uncertainty and impermanence rather than in its character of "absence of impossibility"[70]. We will see in Chapter two the logical traditional interpretation of the concept of possibility, an attitude which has not helped its consideration in biological sciences, where one has to take into account:

> Comment decrire la contingence de l'evolution (la "necessité" du passé) en quel sens l'evolution contient-elle des possible, comment montre-t-on la multiplicité des voies possibles dans la structuration de systèmes biologiques. Debru (2003), p. 95.

---

[70] This is in fact the character that has been considered by linguistics as the basal level for a concordant definition of the possible (Debru, 2003, p. 26).

As Debru remarks the problem of possibility traditionally takes into account the opposition between the notion of necessity and that of contingency: "Necessité ou contingeance, il s'agit là d'un des problèmes philosophiques les plus resistants que l'on puisse rencontrer" (Debru, 2003, p. 23)[71]. In Parmenides' thought, for instance, the impossibility of the co-presence of the categories of being and not being makes the possible becoming something unreal.

> Il non essere non puoi né conoscerlo (ché non è raggiungibile) né esprimerlo; poiché la stessa cosa è pensare ed essere" (Parmenides, DK, fr. B 3, w. 2-8).

An analogous case is that of the gravitational principle by Newton. The introduction by Cotes to the second edition of Newton's *Principia* (1713) made it reasonably clear that it is correct to consider gravitation an *action at distance*; in spite of commonsense opinion by "action at distance" introducing a potentiality is something impossible. And not only in popular opinions, at the same time in fact there were many mechanists philosophers arguing that *real* striking force and traction were more fundamental in the explication of forces transmission[72]. Even among not mechanist philosophers, one for all, Leibniz, it was claimed that proper movement could only be the *result of a contact*, refusing any action at distance. Jammer in his book on the concept of force recalls the ancient Latin sentence "*Corpus a corpore non moveri, nisi contiguo et modo*". Leibniz conception of motion was characterized by the idea of a *real exchange of activities*: *Quod non agit non existit*, (cit. in Jammer, 1957, p. 182). We have already commented how the climate, the Zeitgeist of an epoch is the cultural germinating ground for new ideas but in a peculiar way: it is contemporary its condition and its impediment, the level crossing, or the threshold. As we will better understand in next section, talking about this peculiarity of cultural-scientific interplay, we should more properly adopt an organic metaphor, the constraint, that specifically puts in evidence this character of

[71] See Vuillemin J., *Necessité ou contingence. L'aporie de Diodore et les systèmes philosophiques*, Minuit, Paris, 1984.
[72] See the dispute in e.g. Casini, 1998.

something which both allow and forbids, a process that giving structure, at the same time prevents every other structures to be formed. It is a complex interplay between architectural, phyletic and developmental constrains that have main interplay in species evolution.

> If one looks at Darwinian Evolution, the paths followed by phylogenesis are possible (or generic) ones, yet subjects to structural and phyletic "inertia" such as architectural and phyletic constraints (Gould and Lewontin, 1979). Ontogenesis goes along generic paths as well, the co-possible ones, yet with respect to more restrictive constraints, that are developmental, which are a subcategory of phyletic constraints. [...] There is a superposition and an entanglement of constraints as Gould and Lewontin have clearly enlightened in their distinction of architectural, phyletic and developmental constraints. Frezza, Longo (2010), p. 176[73].

We will better comprehend this process in next section, directly in biological discussion. For the moment we may enlighten some main correspondences for our portrait of the interaction. We have observed the dispute at the time of Newton and Leibniz about the notion of *real* action, which could only properly happen by contact (reality) rather than at distance (possibility). But then the Newton's gravitational law of action at distance has been confirmed and accepted, focusing the idea that gravitational force is expressed at distance. Going to quantum mechanics analyses, then, we have seen another discussion about the meaning of *real-possible* action, which undermined the previous classical description of action at distance, introducing more concretely the idea of complementarity and *inter-action*. In both cases the acceptance of the new hypothesis has not been simple and the great passage made by modern physics stands for a completely new theoretical configuration.

The notion of action becomes to be perceived as possible, firstly in the meaning of not-impossible and then also as something real, comprehensible, even if counterintuitive, by means of physical laws. We

[73] In Chiarelli B. (ed. by), *Human Evolution*, "Variations on the theme of invariants:conceptual and mathematical dualities in physics vs biology",Vol. 25 - n.3-4 (173-185) – 2010. For a detailed analysis on the notion of constraint see, (Gagliasso, 2009).

start to see the mix between reality and potentiality, we become to see the transformation from an action or a reaction into something that resembles much more to our concept of interaction. Something that resembles more properly to a communication that shows its virtual character.

With the notion of complementarity expressed by quantum mechanics experiments, then, we start to see that the mixture of reality and possibility becomes to be configured yet in a new meaning. Briefly, the more we get into reality, such as the structure of microscopic matter, the more we lack in objectivity and we need to adopt potentiality and variability criteria. It is an asymptotic curve, which the more tends to reality the more proceeds towards potentiality while departs from normal deterministic criteria.

We should not lose the occasion of remarking again the importance of potentiality for biological studies, clearly expressed for instance by Jacob (1981). To this end, we may recall the discussion above about physics interpretation of experimental events happenings by means of the parenthesis of an observation. For biological matters, we are rather inclined to think that evolution does not happen in parentheses. Even extinction or genetic drift, could never be considered namely a parenthesis in the sense we have tried to explicit. The course of evolution is more likely to be found *in and intra* parentheses. Living processes are nothing but confined, they are extremely reactive and interactive and moreover a description of them that is expressed by means of parenthesis would not really be satisfying for a theoretical more holistic approach. Just a brief example: the famous recent experiment that has created “the first cellular synthesis”. This rather than being the expected result was an incredible happily serendipity case, a frequent experience in science. This is the effect of complex interactions, interference, constraints always in action in biological matters, which are nothing but predictable in a program way whatsoever.

rather than founding what was to be found, more likely has brought a result that one would have expected in the beginning[74].

II. The psychological sight

Una ipotesi sbagliata è meglio che nessuna ipotesi, giacché il fatto che sia sbagliata non è un danno.
W.J. Goethe

Si la science évolue, c'est souvent parce qu'un aspect encore inconnu des chose se dévoile soudain; pas toujours comme conseuence de

[74] See also Debru (2003) p. 21 for an account on the possible from the standpoint of logic, and Bitbol (2008) for a wide discussion on possibility and Jacob (1981)

l'apparition d'un appareillage nouveau, mais grace à une maniere nouvelle d'examiner les objets, de le considerer sous un angle neuf. [...]. Il implique toujours une certaine conception de l'inconnu, de cette zone située juste au-delà de ce que la logique et l'experience autorisent à croire.

F. Jacob

1.

The beginning quotation by François Jacob above emphasizes the peculiar mélange of possibility and reality always present in every ideation or creative process. More properly here Jacob addresses especially to scientific theorization and science evolutions. The most remarkable element is the focus on the typical insight of scientific working out, what is generally called "serendipity", and which compels this "conception of the unknown, of this zone beyond what logics and experience normally allow to hold".

In this section we will try to see how figures and structures emerge from the unknown, how this invisible interaction between the known and the unknown brings to evidence relations, processes and ideas. This is especially what *Gestalttheorie*[75] has helped to delineate by means of the study of organizational processes, focusing particularly on the notion of interaction between parts and the whole structure, as we will try to put in evidence in this section.

In brief, we will see that the notion of interaction that *GT* proposes is completely different with respect to the atomic mechanical relation of determination that we have enlightened in previous section. Thing that, as we have seen, is true with respect to the coincidence of the physical notion of interaction with that of force, such as the "material" action between two bodies in proximity, as well as for the more proper

[75] From here by *GT*.

Newtonian intuition of action at distance, expressed by the gravitational force.

Here, therefore, we will move from the physical field to approach the psychological standpoint on interaction. The idea in a nutshell is that the notion of interaction in its wider meaning is an emblematic conceptual feature of all psychology that has slowly strengthened its power of explication and thus, as it typically happens, has been more recently diffusing also towards other subjects, as we have described in the introduction. I have proposed to call this process an *epistemological exaptation* from physical and psychological domains towards biological and also communication and media disciplines, which however are not our main target here.

In this section I will try to tell the story of this reinforcement, as we have already seen in physics, trying to put into light some other elements that I find essential for better understanding the concept of interaction. Putting into light a gestaltic approach on interaction the analysis will show in the end a typical polarization of this notion between a deterministic and a multi-factorial point of view:

- a deterministic reference to the concept of interaction by which things are sums of parts and their interactions are result of this sum;
- a multifactorial approach to the concept of interaction by which things are results of complex and seldom emergent processes, thus the interaction is never the sum of the elements.

We will see then, that this same polarization is grounded in a wider theoretical discussion. Progressively we will be able in fact to recognize a typical conceptual antinomy of the thought (which, as a procedure, may recall Kantian antinomies of the reason76) between a determined character (particle, mechanism, determinism, elementariness, analytical, physical, objective, universal,...) and a multifactorial one (wave,

[76] Kantian antinomies are the result of the ambition of the reason to go beyond the limits of the intuition bringing to an unsolvable quarrel between two contradictory positions both rational concerning four main subjects: the world, divisibility, cause and god. See Kant, *Der Kritic der reinen Vernuft*, 1781, Leipzig. English tr.: *Critique of Pure Reason*, P. Guyer, A. Wood (eds) Cambridge University Press, February, 1999.

vitalism, random processes, gestaltic, synthetic, biological, subjective, historical,...).

One should underline that the story that follows, of course is just a conceptual hypothesis, without the claim of an historical exactness or a proper historical aim, but I think that nonetheless it might let us put in evidence some elements which are not so obvious.

Let me precise that for this analysis I have chosen in particular *GT* researches not only for the special attention this approach has addressed to interaction processes, especially from a perceptive point of view, but also because *GT* has permeated its researches, analyses and theorizing with this interactive dynamics itself, or in other words *GT* has provided its same methodology with a "twist of interaction". We think that this peculiarity of a methodology that talking about interaction reveals also an interactive attention in its descriptions and towards other fields is an approach that should be highly considered. In fact from *GT* perspective for example to perceive, to act and to express become parts of a unique characterizing ability of living beings (Rosenthal, Visetti, 1999). Moreover, this same conception will help us to introduce in a sort of resonance effect, a conceptual line, which we will develop in next section, that leads to some recent researches in neuroscience. In particular those that focus a theorization of motion and action which recalls a phenomenological ground (Berthoz, Petit, 2006; Rizzolatti, Sinigaglia, 2006).

We should add as another element of our personal choice – which as we remark does not pretend to offer an historical comprehensive horizon, rather prefers to illustrate some clues for a critical story of the concept of interaction– the parallel that we have found between some elements that we have put in evidence in the analysis of physics (notion of field, complementarity and possibility-probability) and some characteristics that *GT* takes into account for its description of visual field and gestaltic structuring of images and forms.

Moreover, there is a special juncture to be enlightened, for contemporary to *GT* developments, and especially in Germany, one assisted to a great renewal also of physical and biological sciences. Both disciplines were more and more conscious of the dynamical and potential traits in their researches, as a consequence of the establishment of previous century discoveries. On one side in physics, as we have seen, especially with field theory and electromagnetic analyses which lead to wave-particle theorization and on the other side, in biology, with the development and establishment of Darwin's evolutionary theory which gave to biology at least the first ideal consistence of a possible independent science77.

As Canguilhem explains in *Ideologie et rationalite':*

> En resume', en 1859, etaient déjà constitue'es scientifiquement, c'est-a'-dire e'taient en possession de principes heuristiques, de concepts ope'ratoires, de techniques expe'rimentales, les e'tudes relatives: 1) a' l'origine de la vie sous la forme des etres unicellulaires, 2) au de'veloppement et a' la structure e'le'mentaire de l'organisme pluricellulaire, 3) aux fonctions d'entretien et de comportement de l'organisme individuel, conside'r'e comme un tout. Orces principes, ces concepts ou ces techniques ne pre'paraient pas toujours les esprits a' comprendre et a' adopter le mode d'approche darwinien du proble'me de l'origine des espece's. Canguilhem (2000), p. 104-5.

Connected to this very flourishing atmosphere the inter and trans-disciplinary vocation of *GT* is not hidden, they intended precisely

> Un basculement, une ouverture des champs scientifiques vers une conception tres generale des formes et des organizations, ayant vocation a valoir, bien au dela' de la psychologie proprement dite, en physique, en biologie, et bien sur dans toutes les sciences humaines – dans tous les domaines ou' pourraient jouer des phenomenes de repartition et de regulation dynamiques des structures. Rosenthal, Visetti (1999), p. 149.

This inter-disciplinary aspect, which one should characterize as procedural and intrinsic to *GT* theorization, as we said, is another decisive element that we underline in this work. We will see in the third part a parallel with this peculiar integration between theory and practice also from the point of view of logics, and the geometry of interaction in

[77] For an overview on the establishment of Darwinian evolutionary theory see Canguilhem (2000), pp. 101-119.: Mayer, 1994; Continenza (2008), "Evoluzione esviluppo tra divorzi, sintesi e simulazioni" in *Il futuro di Darwin*, (ed.) Calabi L., UTET, Torino.

Girard's work (e.g. 2006).

For all these reasons together and especially the focus on the interactive nature of processes and the attention accorded to physical and biological sciences, in my opinion *GT* approach offers many relevant traits useful also for an analysis on form and development in biological field. In fact these are both constitutive characteristics of biological evolution (all history of biology may be considered as the developing of forms.

Among much and multi-regional literature about *GT* that for many different reasons, one of the most evident being the emigration of some of its members in the U.S., is not at all a phenomenon peculiar to German literature we have chosen to follow Visetti and Rosenthal works for their keen interest in a comparative perspective of *GT* with biological sciences78. This is in fact also our primary issue on the subject.

> C'est à notre avis à leur problematique, à leur cadre epistemologique et methodologique, à leurs demarches theoriques, qu'il importe de revenir si l'on veut veritablement en saisir l'interet pour notre actualité scientifique. Rosenthal, Visetti (1999), ibidem.

In particular, this accent on the dynamics of forms suggests that *GT* could offer new heuristic ideas for the study of individuals and living beings in all the typical expressions of their dynamics interactions, the so called organizational processes (morphology, ontogeny & phylogeny; constraints, architectural, phyletic and developmental; structural stability, individuation through changes, environment, ...).

---

[78] For a French outlook on *GT* see in particular Guillaume P. (1979), *La pshychologie de la forme*, Flammarion, Paris (ed. or. 1937) for a recent discussion of the actuality of Gestalt themes see Rosenthal V., Visetti Y.-M., "Sens et temps de la Gestalt", *Intellectica*, 1999/1, 28, pp. 147-227); for an Italian review see the work of Bozzi and all his school followers (Bozzi P., 1989, *Fenomenologia sperimentale*, Il Mulino, Bologna); (Kanizsa, 1978); in the Anglophone world see the work by Ash M. (1998), *Gestalt psychology in German culture*, 1890-1967, Cambridge Univ. Press, Cambridge and for an outlook especially concerning the philosophical insights of the *GT* see Smith B.(ed. by), *Foundations of Gestalt Theory*, Philosophia, Munich, 1988. The *GT* dialogue with their coevals' philosophical questioning can be seen for instance in Merleau-Ponty's reflections on perception from a phenomenological standpoint , *Phenomenologie de la perception,* Gallimard, Paris, 1945; *Le primat de la perception et ses conseuqences philosophiques*, Ed. Cynara, Grenoble, 1989.

2.

We should overcome now also some problematic elements that nonetheless we remark in this approach. The peculiarity of *GT*, as we have mentioned is a universal approach to experimental research and theorization which synthesizes in a rigorous experimental frame but with a global approach too the description of natural phenomenality which from a strictly atomist-deterministic standpoint revealed some difficulties. This very dispute between mechanism and vitalism, which is in the middle of the context in which *GT* developed, can be considered as a twist of a more general quarrel to which we have already made reference in previous section. We are talking about the ancestral, perpetual, multi-significant and multi-stratified dispute which brings all the various points of a research to the border line of a simple theoretical choice:

- determinism vs indeterminism
- corpuscular vs undulatory
- atomism vs holistic
- mechanism vs vitalism
- physical vs biological
- analytical vs synthetic
- objective vs subjective
- elementariness vs gestalt, and how many more?

Of course one should notice that presenting together all these conceptual oppositions in a general horizon, we are necessarily proposing to consider these opposing standpoints in one-unique frame without remarking their specific and characteristic differences.

As we said *GT* tried to establish itself as a solution to at least some of those very oppositions, for instance concerning the quarrel between mechanism and vitalism standpoints. The cross-section onto the *GT* approach puts into light then an inevitable question. How should one consider the universal character proposed by the notion of the *Gestalt* without loosing the possibility of describing the continuous changing of the evolutionary processes (individuals, species, environment)? This is one of the main questions present also in biological field analyses: *how*

comes stability through variation? And how can identity and variation be kept together by one unique comprehensive approach?
The notion of *Gestalt*, given as a solution to this very problem, proposes two things at the same time. On one side *GT* assesses the continuity of organizational processes in inert and living matter by means of the recognition and then the declination of an organized structure. This is properly the *Gestalt*, which was firstly discovered in the perceptive field. On the other side *GT* proposal is clearly not confined to perceptive ground, but as we have seen, presents also an emblematic paradigm for further studies and beyond psychological analyses.
In my opinion this point is very delicate and requires a keen attention. In order to clarify this problem we will add in the end of the section another variation to the 8 oppositions scheme above:
9. universal vs historical approach
By doing this we will propose in particular to refer to Vygotskyan point of view. We think in fact that Vygotsky's focus on historical procedures may help us in stressing out some difficulties in *GT* approach, but also in proposing some interesting ways of looking at the question. For the sake of comprehension, let us remark again then that although very interesting we will not introduce this discussion from an historical point of view, not even with any intention of completeness, or questing for the genealogy or the heredity of *GT* in psychological and philosophical researches, rather we will closely look at some main reflections and concepts that help in focusing specifically the theme of the development of the concept of interaction from our point of view. This said we would right away plunge ourselves in one example of what we find strikingly interesting in *GT* description of interaction.

3.

Here we see in a quotation by Köhler, that together with Wertheimer and

Koffka is one of the three Berliner fathers of the *GT*, an exemplar case of the specific concern on interaction.

> Su ogni punto di un organismo *agiscono continuamente* stimoli provenienti dall'esterno, *dal mondo* che lo circonda, *e da tutti* gli altri punti *dell'organismo stesso*. *Parti diverse* del sitema nervoso, *vie diverse* dei sistemi vascolari, ecc., *insieme alle condizioni particolari* del punto considerato, *determinano il processo locale* che si svolge in un dato momento, e se tutte quelle *influenze* si esercitassero contemporaneamente in modo disordinato e arbitrario, anche il processo locale e il suo decorso dovrebbero verificarsi in modo arbitrario. Köhler (1938), our italics.

One may recognize a typical example of the attention that *GT* has given to the analysis of organization process especially by means of descriptions taken from the observation of an organism's life. A precise moment in the life of an individual evidently requests a particular dynamical-evolutionary look. The problem is the relation between the locality of the specific process and the global convergence of all the other possible conditioning and influences arriving contemporary from the external and the internal world. This correspondence in fact might bring to a disordered and arbitrary interaction of all processes, thus completely out of control and leading probably to irreversible damages for the individual. Precisely this opposition of order vs random and parts vs totality is the essential argument that interest Köhler here and, as we will see, which he desire to express in new terms.

> Problems of biology cannot be solved in terms of natural science. Our concepts suggest new ways of dealing with these problems precisely in such terms. Köhler (1938), p.134.

We want to underline in particular the word *influences* used in Köhler description above. In fact, nowadays we may easily and very probably imagine translating this term with *interactions*, without changing the argument in its substance. Let us try then the sentence with this substitution of terms:

> "...together with the particular conditions of the point of exam, they

> determine the local process that takes place at a certain time, and if all these *interactions* would apply contemporary…".

It seems to work well. But looking more attentively this is not the only evident correspondence with the notion of interaction. In fact, as we have tried to put into light in the quotation using italics, there are so many other links with the concept of interaction that one may get the impression that all the reasoning is about interaction.
There are in fact *stimuli coming from inside and outside* the organism that *act contemporary together* with the locality of the very process. So, on one side there is a *global* perspective and on the other there is this *locality* of the specific process that is occurring in a precise time and position. Putting these two aspects together in a global analysis is exactly scientist's job, particularly one that studies living beings.
Following the text above by Köhler, we find many other notions correlated with that of interaction such as *coordination of the local processes with needs and the whole organism situation*, or such as the *confluence* of stimuli coming from different sides. In this way we can slowly but clearly see the main idea of *GT* emerging:

> In realtà noi vediamo per lo più che le singole zone ed i singoli organi *agiscono insieme* "come se fossero d'accordo", così che il tipo di *azione comune* dà luogo ad un processo globale ordinato e dotato di senso. Köhler (1938), Ibid.

We find precisely in this conception of zones, organs and functions that act together as "they were in accord" the second of the two main roots of the development of the concept of interaction to which we have made reference: a deterministic versus a non deterministic, or an analytical versus a synthetic approach. Let us clarify then how *GT* position stands into this more general theoretical dispute that we have observed previously. Following Köhler's analysis this contrast between a chaotic disordered sum of actions and an order natural disposition of processes can be ruled neither by a mechanist approach, nor by vitalism. In fact in accord to a mechanist profile:

> L'uomo costringe le forze della natura a seguire percorsi predeterminati,

> facendole agire nelle machine, ossia in sistemi dotati di "collegamenti" del tutto prefissati nel senso della meccanica analitica. Dunque solo imponendo dall'esterno percorsi fissi alle forze e ai processi si ottiene che quanto avviene in un dato punto della macchina sia conforme al compito generale [...]. La maggior parte dei biologi, dei fisiologi e degli psicologi ritengono che l'ordine ed il giusto coordinamento dei processi dell'organismo siano garantiti in modo analogo attraverso i suoi collegamenti morfologici simili a quelli delle machine. Köhler (1938), Ibid.

As well known, according to mechanist approach –which depending from the point of view applies to different disciplines such as biology, physiology and psychology– organisms and their functioning are organized and governed by a prefixed mechanical order, program or design as if they were parts of a machine[79]. There comes to mind the famous metaphor of the man-machine, employed by Descartes and the more recent version of which is the mind-computer metaphor in computational approaches (de La Mettrie, 1747; Cavazzini 2010; Debru 2010). This conception reveals an organization of organisms in completely determined chains of actions and reactions or in the latest version of inputs and outputs.

To get more properly in the lines of our future discussion it is interesting to remark moreover that under this man-machine determination stands a representation of the subject, and not *a man or a woman*, that is *universally* and not *specifically* determined (social, historical, evolutionary, ...). We may also underline with Mecacci (1999) a vicious link in this uncorpored representation of the man-machine because the machine which at first is conceived by the universal subject in the end turns out to be the model for the Universal Subject itself.

> Si crea un processo circolare per cui (*a*) il Soggetto realizza la Macchina; (*b*) la Macchina si reifica, perde i legami di nascita con il Soggetto e (*c*) la Macchina si impone come modello, come termine di paragone. Mecacci (1999), p. 121.

---

[79] Without really entering in the debate we limit ourselves to hint the lecture of Gould (1983) and for the recent debate on the intelligent design, Hawking R., Mlodinow L. (2010), see also Massarenti's paper on Sole24ore (5 September 2010).

We underline this because in this process we see a pivotal step for the definition of the second version of the concept of interaction focused on linearity and signals, opposed to the Gestaltic-geometric one that we are analyzing.
The debate is vast and we do not have the presumption to open this discussion, here we may just briefly underline this idea of an external normative criterion which establishes stability and order and which is clearly opposed to the evolutionary approach of natural variability and individualization process in biology, as we will better discuss in next section.
On the contrary, vitalism, which can be traced back to German Romanticism in the beginning of 19th century, professed a profound analogy between natural and spiritual processes. As we have mentioned in previous section this conception should be ascribed in the horizon of ancient Greeks creed of the *cosmos* as organism. Goethe was one of the advocates of this philosophy professing that the spirit brings in it-self the keys for the comprehension of natural phenomena, by virtue of the morphogenetic power of the reason (Goethe, 1790)80. In particular later in Germany *Naturphilosophie* gave to this ideals a consistent theorization81. This spiritual approach was spread to Europe through all 19th and XXth century, in France especially with the remarkable contribute of Bergson (1907) and by means of some scholars emigrated in the States found a philosophical tendency also there (Whitehead)82. The main point of vitalism was to be found in its analogical and holistic perspective of spirit and nature. For this reason these theories have had important interplay and resonances also in biological analyses previously in Blumenbach's concept of epigenesis, created by a formative drive, *Bildungstrieb* (1781)83, and later in Hans Driesch's *Entwicklung*

---

[80] *Versuch die Metamorphose der Pflanzen zu erklären*, 1790 (Engl. trad. *Metamorphosis of Plants*)
[81] See *Andler, Fagot-Largeault, St Sernin, 2002;*
[82] An accurate analisys of the comparison between romanticim and vitalism with respect to the positivist standpoint is to be found in Gagliasso,2003; Cavazzini, Gualandi, 2009. See alsoWhitehead A. N. (1920), *The concept of nature*, Cambridge Univ. Press, Cambridge.
[83] *Über den Bildungstrieb and das Zeugungsgeschäfte*, 1781.

(1894)[84], blueprint or entelechy principle and to many ideas of his Russian colleague Gurwitsch, generating a style in biology that lead to what now is established as developmental biology[85]. Without the pretention of entering in this debate we should briefly point out that the lines of this topic on forms and intrinsic power of development of organism put into light also a path for the more recent grounding and further development of the notion of interaction meant in a synthetic approach, as we will better consider in next section.

One of the main features of this vitalist tendency that we especially want to enlighten here for its analogies with *GT* is the idea of morphology for living beings analyses.

> La philosophie de la nature, en effet, est d'abord une theorie des formes et de leur genese: une morphologie et une morphogenese. Goethe forge le terme de morphologie pour designer l'etude des etres vivant et, en particulier, de leur forme, entendue au double sens d'apparence visible et de constitution interne. Andler, Fagot-Largeault, St Sernin (2002), p. 76.

The *Urbild* is the primordial image that gives birth to the cosmology of forms of the nature[86].

> Concluons que l'universalité, la constance, le développement l'unité de la métamorphose simultanée, permettent l'établissement d'un type ; mais la versatilité ou plutôt l'élasticité de ce type dans lequel la nature peut se jouer à son aise, sous la condition de conserver à chaque partie son caractère propre, explique l'existence de tous les genres et de toutes les espèces d'animaux que nous connaissons. Cit. in Littré (1838).

We may straightforward notice some evident connections with *GT* ideas: the constant type and at the same time the elasticity of the type produced

---

[84] *Analytische Theorie der organischen Entwicklung*, 1894.

[85] See Gilbert S., *Developmental biology*. Ninth edition, Sinauer Associates, N.Y., 2010. For a beautiful story on the predominant character in biology of the elementariness feature with regards to these considered spiritualist ideas for instance in D'Arcy Thompson and Waddington works that have been reconsidered only later on in the light of a different epistemological culture, see Fox-Keller (2002).

[86] One may see here the idea of a sort of recapitulation theory, known in the slogan "ontogeny recapitulates phylogeny" which from original romantic mould was developed especially by Ernst Haeckel see Mayer 1994, *The Quaterly Review of Biology*. See also all the all commentary by Littre' (1838) quoted above.

by the variability of nature. Anyhow one should put in evidence the main difference, while in *GT* the universality of the gestalt is attained by transformation or isomorphism between the correlation of local and global properties, and as we will see, in the establishment of the "laws of perception", here the emphasis is on the vitalist principle which reflected a sort of pre-established harmony between spirit and nature87. Nonetheless very interesting, rather than propose a comparison with these peculiar philosophical point of views, we prefer to underline directly original *GT*'s standpoint, which by the way, as its conceivers remarked is strictly speaking neither mechanical nor vitalist.

> What is our own situation in this field? To be sure, the machine conception of life now meets with some skepticism. On the other hand, biologists do not yet appear to have much better explanation of organic order. (Kohler, 1929).

4.

From what we have already learned in previous section we could add something to this specific comparison between mechanism vs vitalism approaches, connecting and grounding it also into the point of view of physics. As we have seen, in physics the materialist-atomist standpoint might be traced back to the ancient conception of atoms and particles aggregation mechanism and later was represented by the corpuscular standpoint. This materialist-physicalist position became to constitute also a peculiar epistemological reductionist address. This is known as the positivist or physicalist approach and became a general tendency diffused and dominant in many different fields and disciplines88. Physicalism expresses a sort of ontological principle, the elementariness, found firstly in physics, which should help in determining the structural

[87] For a discussion on the difference between vitalism and *GT* see (Rosenthal, Visetti 1999)

[88] Positivism and physicalism are two main approaches in 20th century philosophy which proposes explanations with a highly reductionist mark, differences in various standpoints are depending from the point of view, the discipline and the grade of reductionist-explicative power one addressed to the theory. This is a wide argument in historical and theoretical standpoint for a recent review see: Tauber A.I. (2009) *Science and the quest for meaning*, Baylor Univ. Press, Waco, Texas.

characterization of phenomena. As a sort of directive principle guiding researches and which is extensible, as a general criterion, to many different domains. We should recall that in the same domain of physics this image of an absolute and universal principle for questing and observing natural phenomena started to be undermined by the conflict particle vs wave and complementary approach.

One of the sign of this epistemological twist is to be found also in psychology, characterizing the entire debate between different schools. On one side the first experimental laboratory of Wundt (1879) leaned on the principle of elementariness characterizing a strong positivist and experimental tendency in psychology and on the other the approaches especially addressing to a phenomenological tradition, such as Stumpf's school89. Is in this context that the *GT* ideals could expressly manifest as a quest for a rigorous experimental discipline but considering the qualitative facts of experience too.

In Köhler's opinion, as we said, the mechanist approach is analogous to vitalism, even if with a nuance.

> Se dunque fosse inevitabile scegliere tra vitalismo e meccanicismo, vincerebbe il vitalismo" Köhler (1938), p. 138.

In fact, in Köhler's mind, the typical vitalistic trait, that of a harmonic order, should not be defined "philosophical, because it concerns an objective fact and maybe the most surprisingly among life phenomena" (Ivi, p. 136). We should add at this end that in *GT* reflections there were many attempts to grant a global phenomenological view to phenomena, rather than in the atomistic-reductionist explanation. In this way *GT* would not want to leave the quantitative-objective-experimental-rational domain, to refugee in the "irrational" realm of the senses, as vitalism approach was considered proposing. One should say then that if *GT* refused to lean on elementariness would not either want to follow its contrary approach.

> Les totalités gestaltistes sont en effet des ensembles articules et

[89] For this history see in particular Dazzi, Mecacci, 1982.

stratifiés, dont l'étude peut être conduite de façon progressive, jusque dans leur constitution physique. (Rosenthal, Visetti, 1999, p.162).

In order to get the philosophical lines of this argument one may recall here the characteristic theoretical context in which *GT* researches were developing. Stumpf's school, to which Wertheimer, Koffka and Köhler attended, attempted to describe a phenomenological science in which the approach was neither strictly mechanist, responding to the principle of authority that in *GT*'s ideas is commonly called physiology of the sense organs (as for instance in Wundt's atomism) nor vitalist90. In this sense *GT* leaned on Brentano's *intentionalität* concept which introduced an objective criterion for the understanding of *phenomena phenomenality*. We cannot enter in this debate properly, for an outlook on the development of the concept of intentionality and phenomenological reflection see (*e.g.* Smith, 1989); nonetheless we need to briefly introduce some main traits. In fact the idea of an internal, but not private, access to the outwardness of phenomena was due to Brentano's intentionality conception as "conscience of something". According to phenomenological standpoint, this intrinsic complementarity of the phenomenological appearance of bodies and objects with the conscience the subject has of them makes possible the rejection of private and solipsist character of mental contents on one side and on the other reveals the possibility to ground the experience in the constitution of the very experience it-self91.

> Occasionally I find myself in the attitude of "admiring". But admiring never occurs as a fact by itself. It always is "of something". Nor is there ever the slightest doubt as to the object to which the attitude refers. [...] Admiration, like other attitudes, has a direction. Köhler (1929), p. 323.

We can underline straightforward this trait of the phenomenological trait of intentionality, such as a *direction*, a sort of anticipation in the apprehension of something that we will see described also in recent

[90] See Dazzi, Mecacci, 1982.

[91] This debate brought also to nowadays reconsideration in neuroscience of phenomenological approaches in the so called "naturalizing phenomenology" (Petitot et. al. eds., 1999), see next section.

neuroscience researches.

GT's attempt is clear, it is the result of an interest in the physical-quantitative experimental approach but together with a more global outlook on a qualitative characterization of phenomena.

> Under normal conditions, objective experience depends upon physical events which stimulate sense organs. But it also depends upon physiological events of the kind which we now wish to explore. The physicist is interested in the former fact: the dependence of objective experience upon physical events outside the organism enables him to infer from experience what those typical events are. We are interested in the latter fact: since experience depends upon physiological events in the brain such experience ought to contain hints as the nature of these processes. In other words, we argue that if objective experience allows us to draw a picture of the physical world, it must also allow us to draw a picture of the physiological world to which it is much more closely related. Köhler (1929), p. 57.

This *GT* focus on the physics-physiological nature of phenomena is the so-called "psychophysical isomorphism" that has been highly criticized and about which we will spend some discussions later on. For the moment, let us add with this nuance focused by *GT* another point to our scheme of oppositions:

10. quantity vs quality criterion.

The subjective side of the experience is integrated in an objectivity characterized by a qualitative feature; in this way it becomes possible the proposal of a proper science of the qualitative aspects rather than a science only focused on the quantitative traits (Rosenthal, Visetti, 1999).

> Les "lois" quantitatives qu'il leur sera possible d'etablir seront tenues par eux pour des simple regularités toujours révocables selon les individualités observées, et non pour des lois deterministes et prédictives. Rosenthal, Visetti (1999), p. 156.

Therefore we may better understand Köhler's proposal that the two approaches (mechanist and vitalist) about natural phenomena should be substituted with a global perspective that is objectively determined, as such in the mechanist attitude, but keeping that sort of "causal harmony" which would be more tuned with the vitalist approach (Ivi p. 137).

The main problem in the mechanical approach is the elementariness of the stimuli.

> While a sensation is supposed to occupy its place in the field independently, i.e., determined by its local stimulus alone, the curious thing about the qualities which Ehrenfels introduced into scientific psychology is their relation to *sets* of stimuli. Nothing like them is ever brought about by strictly local stimulation *per se*; rather the togetherness of several stimuli is the condition which has these specific effects in a sensory field. Köhler (1929).

Köhler makes the example of the glass of water with soap. The fuzzy condition of a first observation reveals in detail a more organized dimension in which the system depends upon local characteristics in their relations to one another. Only considering the properties in their interactions one takes advantage of a reliable explanation. Otherwise one should imagine or a mosaic or anyhow a very poor illustration of the experience. If we remove all the possible interactions to our panorama of sensations, we get an anonymous portrait in which all the dynamics is to be restricted to the elements alone, considered separately, the distribution of which as a whole resukts nothing more than a geometrical element.
Taking in exam also the stimulus-response formula it seems that its power of explanation is misleading, in fact it considers that any local sensory fact is strictly determined by its stimulus.

> Consequntly the characteristics of the stimuli in their relations to one another can play no part in the determination of local sensory experience. They can do so only if processes in the brain are free to interact. Interaction in physics, we remember, depends throught on the "characteristics in relation" of the interacting facts. Köhler (1929).

Mechanism, such as the stimulus-response model of behaviorism does not foresee that the instances of local sensory data depends upon the relation between local stimuli and stimuli in their neighborhood. Köhler makes the metaphor of a railroad train which remains on its trucks because the power of its engine has no influence upon the direction of the train. In the same way order in association and recall in stimulus-response model is just a matter of pathways, and the nature of the processes which travel along these pathways has no influence upon their course. In other words behaviorism model neglects the fact that in between the stimuli and the response occurs the process of organization, in particular the formation of group units in which the parts acquire their proper characteristic, or new, emergent ones, we would say nowadays (Köhler, 1975, p. 200). The constancy of brightness for instance depends upon the illumination and brightness of the surrounding field to the brightness of the object under observation.

> Ciò che ci manca è un punto di vista che non tratti i singoli fattori isolati uno dall'altro; e lo si potrebbe cercare già oggi, col solo pericolo che quanto troviamo debba forse essere enunciato provvisoriamente in una forma alquanto astratta. Köhler (1938), Ibid.

One may notice the confidence that reveals such an ultimate hypothesis compared to nowadays fragmentation of scientific disciplines and typical precautionary cold terms in theorizing activity. Köhler's belief in a solution of the atavist dispute mechanism vs vitalism / quantity vs quality / analytical vs synthetic that characterizes philosophical and scientific theories is the sign of a great self-confidence. It is quite easy to recall in this attitude a usual tendency at the beginning of a theoretical construction of a theory by which words are the reflex of the enthusiasm of discovering and creating.

Despite its concrete realization nonetheless Köhler's proposal is becoming more and more delineated. The idea is an *internal organizational order*, which could allow gathering together various elements and which does not simply consider them in their isolation. In other words, the main point is the establishment of the primal founding character of organization process and *dynamic self-distribution.*

> **WHEN the Gestalt problem first arose, nobody could foresee that later it was to be closely related to the concept of dynamic self-distribution; nor were the facts of sensory organization immediately given the central position which they deserve.**
>
> Köhler (1929),

p. 173.

These properties, as we start to comprehend, are result of the organization. More properly it does not happen to have a mosaic of sensations as we already said: the sensory world as such is endowed with specific attributes which it owes to the same organization.

> Our view will be that, instead of reacting to local stimuli by local mutually independent events, the organism responds to the pattern of stimuli to which is exposed; and that this answer is a unitary process, a functional whole, which gives, in experience, a sensory scene rather than a mosaic of local sensations. Köhler (1929).

This means also a typical phenomenological attitude, by which the sensory world as such does not exist, we produce and contemporary we are product of our experience.
Köhler makes the example of some training experiments on animals and humans92. The subject shows in its behavior that

> It seems to be a general rule that retention which refers to the organization of facts is more persistent than retention which refers to individual facts as such. (Ivi. p. 281)

We seem able to remember the general structure of an object more properly than its particular features. Nonetheless there were two contrasting facts:

- the property of a certain invariance of the visual shape had been put into light93.
- but an important property that was put in evidence was the "transposition" of this invariance.

There are evidently certain traits or shapes that are perceived in their stability, but at the same time a capacity for transposing them should be

[92] In particular here Köhler refers to Lashley's works and also on his personal experiments on chicken (p.199-200). See also van der Veldt, *L'apprentissage du mouvement et l'automatisme*, Vrin, Paris, 1928, particularly for the importance of the actual intention of the subject vs recalling experience.
[93] See C. von Ehrenfels' works on shape and forms, *Über Gestaltqualitäten* (On the Qualities of Form, 1890), and its comment in Köhler 1929.

also attributed to our perception: certain condition must be kept constant if one wants the transposition capacity to be attained. Or, in other words, the relations among the stimuli involved must remain approximately the same when the stimuli themselves are changed (p. 198). For instance one should think of a melody which may be given in different keys and yet remains the same *qua* melody (Ibidem).

Köhler precisizes that in physical systems events are determined by two sorts of factors:

- forces and all factors inherent in the processes of the system which are called the dynamic determinants of its fate.
- a second class formed by characteristic of the system which subject its processes (1) to restricted conditions which are the topographical factors.

The example that Köhler illustrates is that of a conducting network in which the electrostatic forces of the current represent the dynamic phase, while the geometrical pattern and the chemical constitution of the network are the topographical conditions which restrict the interplay of those forces. An important remark is that while in natural system dynamic factors are at work special topographical conditions may be at a minimum in one case and predominant in another…(p.112).

Köhler propose a parallel between the relation of transposability with topographical conditions, which are "stable" with regarding main proportional structures and dynamics.

> The "extreme" relation between dynamic factors and imposed topographical conditions is almost or entirely realized in typical machines. The variety of different one-way functions which may be enforced in one such system or another is enormous. But the general principle is everywhere the same. Sometimes, it is true, dynamics is allowed a bit more freedom than the absolute minimum. Still we do not construct machines in which dynamic factors are the main determinants of the form of operation. Köhler (1929).

The important remark that Köhler makes is that this capacity in a first time has been attributed to intellectual capacity rather than to very simple and basal organizational perceptual-cognitive structuring. He adds that once the basal role of the organization principle has been recognized one should start to realize more specifically its proper dimension in biology, particularly in ontogeny (p.199).

> **and movements. At this point, just as at many others, it seems to be the natural fate of Gestalt Psychology to become Gestalt Biology.**
>
> Köhler (Ivi p.359).

Nonetheless as we will see this idea as been kept much more as a horizon for the researches than eventually brought under a fine analysis (Rosenthal, Visetti, 1999).

4.

> En effet, une fois reconnu le charactere primordial de l'organization, notamment dans la perception, il importe de la comprendre d'une facon qui reste compatible avec les sciences de la matiere et de la vie. Mais comment cela se peut-il, quand l'organization a decrire determine paradoxalement le local par le global, les termes par leurs relations, les elements par leur ensambles, les structures par leurs processus? Rosenthal, Visetti, (1999), p. 168.

As Rosenthal and Visetti remark, at first sight one may get the impression of an opposition of *GT* approach, which explains the local by the whole, the structures by their relations, with the objective standpoint of physics. This was in fact one of the main problems that *GT* had to solve, wanting to be considered properly as an experimental science. Köhler proposed a hybrid solution (1920) taking into account a general model for a brain physiology apt to grant the continuity between physics, biology and psychology domains94. Nonetheless:

---

[94] Köhler W., *Die physischen Gestalten in Ruhe und im stationaren Zustand*,1920. For the

> Une conception physicienne des structures, dans une certaine mesure compatible avec leur manifestation phenomenologique, prend ici le pas sur une approche specifique au vivant (Ibidem).

We need to better specify then this peculiarity for the possibilities it opens towards a biological perspective, but also for its specific difficulties (Rosenthal,Visetti, 1999, p. 173). We want to underline here this powerful idea of a physical conception of structures that is nonetheless considered together with an analysis of the different levels of phenomenality at which these structures are functioning. We think in fact that this approach might be a utile instrument for nowadays biology theoretical researches (such as System biology or complexity-emergences approaches). Köhler delineates a non contradictory but complementary explanation: on one side the form and the dependency between local and global functioning is specific and manifests concretely in a precise occurrence, on the other side these very configurations may be readopted in other situations, they are functioning, in other words, as isomorphisms. This is the character that grants the *universal* trait to the dynamics of forms. In fact, the specific relation between a local and a general process in Köhler's reflections is not a peculiar characteristic of life, but is a *universal* feature of nature including inert matter.

> Infatti la dipendenza delle proprietà e delle funzioni di una parte dalla sua posizione nella totalità è una caratteristica fondamentale di tutte le strutture, anche quelle inorganiche – delle quali si occupa la teoria della gestalt. Köhler (1940),p. 138)[95].

We will have to specify, anyhow, *how* this dependency of a locality with its correspondent totality may have in Köhler's opinion universal features. He talks namely about the dependency of properties and functions of a part of a system with respect to its specific position in the totality, which is in fact a very general reference. This should be noticed because as we would see more in detail in next section talking in biological terms, we will consider an analogous relationship, but in more specific terms: the interaction between the locality of a precise process

first suggestion on the subject given by Wertheimer see (Wertheimer, 1912b?).

[95] See Köhler (1938) critics on Driesch's principles of vitalism p. 138.

and the global landscape of the individual life that goes together with the maintenance of the structural stability of the whole organism (Bailly, Longo, 2010).

5.

A first clear element of the perceptual experience that had been put into evidence is its organized structure. We have seen then how this standpoint correlates to mechanist vs vitalist problem and how the *GT* proposal is leaning on one side on the topographical characteristics vs dynamics of the parts and on the other on the intentional character of the experience. We have nominated this a "qualitative" characterization of the perception. Following the text we notice a particular passage that in our consideration leads to put in evidence many different philosophical and psychological references all focusing on the perceptive constitutive character of experience.

> Noi vediamo appunto davanti a noi un "libro", una "matita", un "calamaio", ciascuno staccato dallo sfondo [...] – e non vediamo invece al posto di quegli "oggetti", un mosaico uniforme di sensazioni che riempie punto per punto l'intero campo visivo, senza che abbiano risalto le differenze qualitative. Quell'articolazione in oggetti è senza dubbio un dato immediato della nostra comune esperienza; questo mosaico arbitrario di sensazioni è invece altrettanto certamente un postulato formulato solo in base a una concezione teoretica. Köhler (1938), p. 141.

A clear argument that we can underline thanks to *Gestaltic* approach is that in our perception *anyhow we discriminate*. Again, we never see a fuzzy mosaic of sensations that holds our visual field. Whichever kind of immediacy we may have in an observation of a phenomenon, nonetheless this is built by means of a perception that discriminates, via *minima* and *maxima* areas of saliency. Not only, we may add that there are many more possible forms, or configurations, for which we are blind. We perceptively discriminate only some of the multiplicity of possibles.
This analysis has various points in common with many other approaches

to visual perception and perception in general. We may recall some of them which for our target are the more inherent to this discussion: Husserl's description of the entanglement of the perceptive experience (1912), Gibson ecological perspective (*The Ecological Approach to Visual Perception*, 1976), neurophysiology researches made on one side by Berthoz (*e.g. Le sens du mouvement*, Odile Jacob, Paris, 1997) and on the other by Rizzolatti's group description of mirror neurons mechanisms (Rizzolatti *et al*. 2004).

> Essa insiste soprattutto nel richiedere che si ritorni all'osservazione ingenua, affinché non sfuggano proprio le caratteristiche più salienti del campo percettivo. Köhler (1938), p. 141.

It is very interesting that there is quite the same definition in Husserl, which in fact had been more than a source of inspiration for the *GT*. The "ingenuous examination" reminds quite literally the topic of phenomenology resumed in the famous "slogan" by Husserl "Towards things themselves" which conversely recalls also a quotation by Goethe "Non cercare niente dietro ai fenomeni: essi sono la teoria" (1958, p. 203).

Another common trait with phenomenological investigations is the accent on direct experience.

Therefore it is not a case that two different recent and well known proposals in neuroscience, both recalling phenomenology (Rizzolatti, Sinigaglia, 2006; Berthoz, Petit, 2006) used a similar description of the perceptive experience. Nonetheless, while both recall Gibson's ecological perspective (1979) on the contrary none of the two mentions *Gestalt* theorization, as we will better see in next section.

Thus, for better comprehending this reference to phenomenological and ecological investigations, we should say that in Husserl's theory in the field of rays of intentionality in one perception there are always some of them which are not apprehended. We perceive a thing through our intentionality, which in fact as we said literally means "consciousness of something". In Gibson's ecological theory more specifically the objects are made "for" something; for instance, a cup is perceived as "for drinking", a spoon as "for eating" and so on. We think is interesting to

remark this historical evolution as a possible path from the philosophical description of intentionality (1913), passing by the *Gestalt* description of visual field (1929), till the ecological perspective (1979) and recent neurophysiology works (2006) that we further analyze in next section.
We want to enlighten in fact a specific trait which is common in all these standpoints: intentionality, *Gestalt* and ecological perspective do not make any reference to a possible notion of *information* in perception and experience. All these conceptions do not require something like information, a sum of digits that is transmitted, rather things are transmissions or vehicles of transmission themselves. This means essentially two things. First, one cannot possibly have or detect this sort of quantum of information and secondly, there is always a partiality, or an incompleteness in the process of understanding. In physical terms there is always the limit of uncertainty of the analysis, of which reminded Heisenberg, as we have previously seen that is the result of the interaction with measure instruments. The paradox of a physical phenomenon in between of a reality and a possibility is explained by the fact that the function of probability represents the experimental situation in the moment of the measurement, including also possible errors. The function always refers to two things at the same time: a fact and our knowledge about it, which means the contingency, the fact that another observer could possibly describe the same conditions with a more precise grade of definition. This means also that the function of probability that from these initial conditions calculates the probability for another further time, at the same time *does not represent* in itself the *real course* of the events *that is happening* along different times; rather a tendency of the events, which is always present as we said before.
The notion of intentionality is also strictly connected with the concept of possibility, such as the open infinity of rays of intentionality always present in our field of experience, named by Husserl the *Abschattung* phenomenon. In other words: in a perception there is always something more, or something left that one *does not see*. When one looks to a page, for instance, one sees just a face of it, and also of a figure or of a hand writing and so on. Resuming there are two main facts, one of which

should be considered in its polarity:

- the perceptual experience has an organized structure: nothing by nothing, experience as such is not possible.
- whichever perception it is perceived in the experience it is attained through a discrimination. This idea allows to describe in particular a polarity scheme by which there is a possibility of experiences always possible in the experience we make and thus that there is always something more, changing the point of view when we see there is always something less; from another standpoint this can be correlated to physics consideration of measurement instruments entanglement with observation, relevation and description of reality; from another point of view again, one may say that we see only inside this peculiar function of intentionality, on the ground of an intentionality process which is already opened by our entanglement with the experience, o in other words we are able to see only with the behalf of a ground.

We will better see in next section this important distinction between the idea of a quantum of information and the potential of variability in natural phenomena that all the theories we have mentioned here may help to clarify. We should see now how from all these elements the precise interactive notion of *Gestalt* could emerge.

6.

The employ of *illusions* in *GT* as proofs for demonstrating the appearence of *Gestalten*, which for the moment we can define a *multiplicity due of an order*, has become famous. In particular this same idea of disequilibrium in the recognition of a bistable figure or in a visual illusion became of a high importance, as a *mark* for a gestaltic approach (Rosenthal, Visetti, 1999).

> Les gestaltistes accordaient la plus grande importance a' ces situations ou' l'organisation perceptive bascule, a' partir d'une region qui soudainement change de statut et entraine, d'un coup, tout le reste a' sa suite vers une configuration differente. Ils le voyaient comme un modele

> de la productivite' de la pensee, en tout cas, un correlat perceptif de ce moment de discernement, ou insight, ou' l'organisation du champ soumise a' la tension d'un probleme debouche enfin sur une solution. Rosenthal, Visetti (1999), p. 148.

Let us see how it works in concrete. In Figure 1., we firstly see without any prejudice some horizontal rectangles linked by some little lines. Only when we become aware of another possibility the shorter sides of the rectangles get unified with the little lines becoming "a unity", which we easily recognize as the letter "H" of our alphabet.

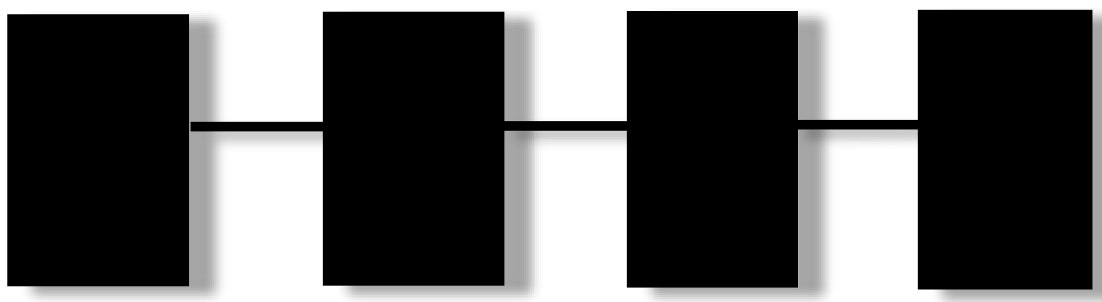

Fig. 1.

The first approach to the figure does not link back to some previous experience it shows something directly, ingenuously and immediately, via some "autochthonous factors" (Köhler, op. cit.). Only after a while, with the help of other mediated factors one becomes to see something else. That's why Köhler talks about the "autochthonous factors", which are not made by the experience (or experience-directed), rather they reflect a spontaneous form of organization of our perception which is "objectively determined" (Köhler, 1938, p. 144).

> "Oggettivamente" significa qui piuttosto: in armonia con le caratteristiche qualitative e topografiche di una data costellazione di stimoli, e dunque proprio il contrario di una segmentazione innaturale che si realizza per l'azione coattiva di un meccanismo anatomico. Köhler (1938).

Köhler sees in these autochthonous factors a process that is a natural tendency to articulation in objects or better in "configurations" that are named, in fact, literally *Gestalten*.
As Rosenthal and Visetti suggest:

> Forme, figure, configuration, structure, ensemble [...] sans compter d'autres acception: personnage, figure historique; complexe d'evenements indissociables; ou encore les tournures telles que *Gestalt annehmen*: prendre forme, prendre tournure, se concretiser. [...] dans la version-princeps due a' l'ecole de Berlin, *Gestalt* signifie une structure dynamique incarne'e, une configuration concrete, qui n'est ni une simple apparition, ni une idee abstraite, mais une organisation indissociable d'un support, en meme temps que transposable a' d'autres. Rosenthal, Visetti (1999), p. 148 and note 1.

A *Gestalt* then properly segregates as a relatively independent part of the visual field. It has properties that are not explicable by means of the mechanist hypothesis of the formation of visual field: from indifferent elements that are simply juxtaposed. As Kanizsa (1978) reminds, the term *Gestalt* is not only used to mean the result of an organizational process, but also to mean the structural properties of the process it-self, for distinguishing it from mere juxtaposition and casual distribution in visual field. It’s interesting what follows:

> Queste proprietà sono d’altra parte sempre presenti nella nostra percezione, sicché fino a pochi decenni fa il problema che esse pongono non fu nemmeno visto. Köhler (1938, Ibid.)

We need to remark another thing, which is yet again common also to phenomenological tradition, and that we may resume in the sentence: “Is not evident what is evidently under our eyes”. There are two main possible interpretations of this. On one side this means that it is not obvious that what is in our visual horizon appear to us. And we should remark that is not only in a literal meaning, evidently. In fact Köhler refers to the strength of the mechanist standpoint which, immersed in its dogmatic attitude, could not see some phenomena, such as the existence of Gestalten, that were instead “at sight”. On the other side this fact means also what Husserl calls the “naturalistic attitude of science” (*Ideen*, 1912), the idea that we have a tendency to approach to the things and the bodies that we find in our world as something which is *already given*. Later on Canguilhem has talked about this fact as a terrific attitude of the thought (see next section). In this attitude we simply collect series of *data* and given objects, without asking *why*, *what* and *how* we find and see them. We see in this remark of *GT* of the not-immediacy and not natural vision of things an important warning for researches and developing scientific theories, as we will better discuss in next section.

7.

We can now sum up Köhler’s text we have commented till now and trace back all the references to the concept of interaction that we have found:

- influences
- acting together
- commune action
- interferences
- transversal tracks between singles routes

- juxtaposition of contrasting actions
- mosaic of sensations
- articulation
- tendency to an articulation
- reciprocal belongings

Reading Köhler's quotation again now we become aware that the text is all about *organization*, but moreover that the main topic underneath is *interaction*. He selects so many different forms to talk about it that it may remind us of Ghirlandaio's pictures, where a face appears from an harmonic mix of vegetables and fruits or a still-life picture full of vegetables, fruits, flowers and birds, that are all traces or metaphor of a "still life"; or yet again those symbolic pictures, especially Medieval and Renaissance ones, in which after a deeper look we see that everything in the background is a sign for the main scene in the front of the picture.

We may be already satisfied with this sketch, observing that all these concepts together delineate a nucleus of the interaction concept that converges on the focus of organization, multi-factorial criterion, structure as a whole, emergent proprieties, synthetic prospective, ...

But nevertheless, after some lines the term distinctively appears:

> Attualmente si tende a spiegare anche il contrasto cromatico simultaneo – anziché con un grande numero di "induzioni" indipendenti tra coppie di punti – mediante l'interazione funzionale tra eventi *gestaltici* che determina il colore locale in base alla posizione della zona considerata in una totalità più ampia. Köhler (1938), p. 159.

The functional interaction determines the local property – that we will call later a *locality* or a specific *locus* – with relation to its position and with respect to the whole totality. The two main properties involved in this process are "figure" and "ground". In Figure 2. a star is shown on the left, while on the right we see the same star but inserted in a circle. After a certain amount of time observing the figure we do not see the star anymore and in a second time we start to see another star made this time by the three bigger sections of the design. Further on, again this figure disappears and we come back to the previous one and so on.

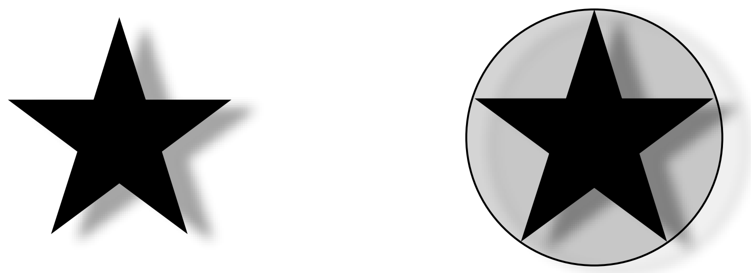

Fig. 2 Ground and figure.

This configuration results made of two distinct parts, and no matter which one of the two is perceived as the plain star, the other becomes immediately the empty ground.

> In contrapposizione a questo modo di apparire, si designa il carattere dell'altra zona come quello di una "figura", e ciò perché solo l'area che appare compatta e materiale ha una realtà come *gestalt* o figura, mentre lo sfondo appare come un'area indifferente e priva di forma, sulla quale (anzi un po' davanti ad essi) la figura è posta. (Ivi, p. 151).

If we look again at the star on the right, aware of Köhler's definition above, we see that the two surfaces alternatively segregate, becoming independent unities of the visual field, such as proper *Gestalten*. These are in fact organized structures with the property of materiality or *plenum* that confers them an identity detected from its *ground*. In fact, this same individualization process of *Gestalten* determines at the same time the structuring of their *proper ground* and vice versa in a perfect *polarity*.

Köhler proposes then to quest for a specific field of research, which should put into a dynamics this static process. He calls it the possibility of a reconstruction of the ground of all different senses during evolution in a sort of syncretism.

> Questi punti di vista acquisteranno forse col tempo, per la fisiologia e per la biologia, un'importanza ancor maggiore di quella che abbiamo loro finora attribuito. Ma le strutture percettive temporali sono fino a questo momento meno note delle strutture simultanee, sicché dobbiamo limitarci a questo semplice accenno (Ivi, p. 153).

8.

So, let us put up the puzzle. The first element we have remarked is the relation in an organism between the *locality* of a process and the *global* convergence of all possible conditioning and influences arriving contemporary from its external and its internal world. This connection can apparently be realized via a chaotic and disordered sum of actions or rather by virtue of an order and natural disposition of processes, which in other terms seems to make sense. We have remarked, then, Köhler's critics of the solutions that mechanism and vitalism approaches have offered to this sort of problem. Consequently, we have followed him in his proposal that the two approaches on natural phenomena should be substituted with a different global perspective, which should be objectively determined, but which underpins at the same time an organization a sort of "internal harmony".

The *Gestalt* is thereby the solution given by Köhler to this question: the result of visual perception "autochthonous factors" which respond to a natural tendency in visual perception to an articulation in objects or better in unities of configuration. So, the *Gestalten* reflect an internal harmony, which is at the same time objective and natural.

We have underlined also the general interest of *Gestalt* theorization in focusing experience and life phenomena at different levels of phenomenality by means of their organization and the peculiar selection of unities of analysis. In particular, those unities should be the appropriate ones for studying the reality of the phenomenon, especially by virtue of a rigorous method, which should be apt to get those unities as natural ones as possible (Kanizsa, 1978).

As we said, the *Gestalt* more generally is conceived as a universal organizational feature of natural phenomena in general. We have proposed that this argument is at the basis of the concept of interaction. In particular, we may put in evidence how two main routes have been developed from these lines in psychology. A direction of the evolution of the concept of interaction stands with the mechanist idea of organization. It implies completely determined chains of actions and reactions or inputs and outputs. While another direction takes into account more connected, or holistic, aspects that combine together a specificity of factors or processes with their proper position in the whole configuration of the organism. As we will see more in detail in next section, between these two meanings of interaction we retain especially the second in an analysis of the organization of an individual, even if more generally. In particular for a description of a living being we consider the utility of the interaction between the *locality* of a specific process going on in an organism and all the possible *global* landscapes of the individual life together with the necessity of the maintenance of the *structural stability of the whole organism*. We underlined therefore a personal argument correlated to what we will analyze in detail in next section. The problem concerns, in accord with *GT*, the mechanist idea of an external imposed criterion of fixity and order, the idea that this organization should be brought by "information" rather than be the result of natural variability and organisms' process of individuation.

Going back to our summary, we have put into light some more general epistemological aspects. We have observed that the *GT* helps in enlightening a fundamental fact: it is not obvious that what is in our visual field may appear to us, and not only from a literal standpoint. There are many possible illusions in our perception as well as in our intellectual understanding of the world. In fact, recalling again the definition by Fox Keller of the epistemological culture (2002), we could say that what we see is what we are just culturally able to see.

This is one of the main critics, from this epistemological point of view, that one may advance to *GT*. The question that we enlighten contrasts in where putting the focus with regards to the *universality* of autochthonous factors and the *fixity* of the same *gestaltic* criteria for inert and living matter. In fact, as we said, the *Gestalt* in Köhler's standpoint is conceived as a *universal* organizational feature of natural phenomena in general. We prefer to enlighten, in spite of a universal trait that unifies all natural events in one big general explanation, how all phenomena and we all exist temporarily, always in *a* history and inscribed in the evolutionary process. This means that looking at living phenomena it might be more useful to establish the main focus on variability aspects and their interactions rather than with a priori universal traits.

9.

On these lines one should remark a critic that has been at the center of the detractors of *GT* that allows us to add some elements that will help us in understanding the opposition between universality and historicity approaches in natural processes descriptions. It concerns the hypothesis of the "psychophysical isomorphism". In Köhler's standpoint there should be an isomorphism between the phenomenal (and one should add, subjective) experience and the spatial-temporal organization of its cerebral underpinnings. Or, in other words consciousness and its underpinnings are not two objects that are related in some way, rather they are two aspects of the same reality. The isomorphism concerns in fact their structural identity.

> L'ordine di cui si ha esperienza nello spazio è sempre strutturalmente identico a un ordine funzionale della distribuzione dei processi cerebrali sottostanti. Köhler, 1949, *La psicologia della Gestalt*, pp. 48-49.

This hypothesis leads to the possible assumption that *GT* is nonetheless built on the basis of a physicist and a materialistic reductionism. *GT* detractors in fact propose that it is a theory whose main aim is the comprehension of psychic life trough physiological processes and by means of laws that are themselves reduced to physical ones. We agree with Kanizsa (1978) that:

> Solo se per riduzionismo si intende una spiegazione dei fatti biologici e fisiologici secondo le leggi della scienze della natura, allora la teoria della gestalt è una teoria riduzionista. (Kanizsa, 1978, p. 43).

Thus we prefer to say that *GT* is inscribed in general in a materialistic approach, which does not imply by itself or by necessity a reference to a physicalism (see, Frezza, Longo, 2010).
Anyway, it is not our aim here the contribution to this discussion96. Nonetheless we express our modest opinion about the extension of the psychophysical isomorphism which would lead to a universal explanation that starting from the recognition of "*universal* laws" of something (here for instance the visual perception functioning) may then be projected on other realities. We do not have the possibility to open this discussion, which by virtue of its worldwide connections opens an entire chapter of history and philosophy; anyhow we suggest to read a magnificent text by Paolo Bozzi concerning the philosophical and scientific foundations of *GT* (Bozzi,1988).
As we have hinted above, whichever idea of the psychophysical isomorphism or parallelism one has, this critic is a useful point apt to enlighten the complementary opposition between historical vs universal criteria approaches. This step is crucial for our work, as it leads more specifically into nowadays neurophysiology researches, which we will further analyze in next section. Moreover it shows many elements in common with Fox-Keller conception of epistemological culture, to which we are making reference in our epistemological considerations. And finally, but not secondarily, because it helps to better contextualize the two opposite paths of the concept of interaction that we are analyzing.
We could put into light in particular a possible opponent to universal trait in the psychophysical isomorphism with Vygotsky's developmental studies[97]. This path, which again wants to be circumscribed to present

[96] For a documented debate we hint to read the text by Kanizsa (1978).
[97] For the central reference of Vygotsky's thought see in particular Vygotsky (1934 in 1999), trad. It (1966) and more generally on soviet psychology see Mecacci (1977); Mecacci L., *Brain and history: the relationship between neurophysiology and psychology in Soviet research*, New York, Brunner/Mazel, 1979.

investigation on interaction rather than proposing an historical analysis of psychological theories (Mecacci, 1999), would help to put in evidence this strong opposition between analytical vs synthetic approaches. We consider this a pivotal element for developing further biological studies and for characterizing the evolution or the epistemological “exaptations” of the concept of interaction.
A clear argument in Vygotsky study is a specific interest in a interaction conception of the cognition rather than in an atomistic profile, such as in the *GT’s* approach that we have remarked.

> The atomistic and functional modes of analysis prevalent during the past decade treated psychic processes in isolation. Methods of research were developed and perfected with a view to studying separate functions, while their interdependence and their organization in the structure of consciousness as a whole remained outside the field of investigation. Vygotsky (1934), chapter 1.

And some lines further we observe another important element in common with *GT* theorization, which opposes to the structural behaviorist model of stimulus-response and to the elementariness approach. We can recall Köhler’s metaphor of the trucks of a railroad train which prevents the consideration of its dynamic.

> It was taken for granted that the relation between two given functions never varied; that perception, for example, was always connected in an identical way with attention, memory with perception, thought with memory. As constants, these relationships could be, and were, factored out and ignored in the study of the separate functions. Because the relationships remained in fact inconsequential, the development of consciousness was seen as determined by the autonomous development of the single functions. Köhler (1929).

The conclusion is that psychology should make these relations and their developmental changes the main problem, the focus of study, instead of merely postulating the general interrelation of all functions. Thus Vygotsky propose a concrete an immanent and historical procedure rather than abstract or one detached from experience. And in this sense Vygotsky made the main interest of his the study of the interdependence of the processes their correlation and interference in the evolution of the mind in a genetic-developmental perspective. But in doing this again the focus is important, it is in fact developmental psychology but Vygotsky's point of view on the subject is made on an essential demarcation.

> The phylogenetic history of a man's practical intellect is closely linked not only with mastery of nature, but also with mastery of himself. Vygotsky (1999), p. 63[98].

In subjecting to his will the process of own reactions, human beings are able to overcome a substantially new relation with the environment. This is done especially coming to a new functional exploitation of elements in the environment as "stimuli-signs" which we use, depending on external means, direct and control our own behavior.

> Internal regulation of activity arises initially from external regulation. Reactive action elicits by man himself ceases being reactive and becomes goal-directed. Ibidem.

In this horizon we see that there is a precise demarcation which opposes to the focus on universality and rather points out the contingency, the historicity of our experience by means of "stimuli-signs". Vygotsky recalls Bühler discoveries of sticks used by Celebs populations to replace human voice or anyhow fulfill a function similar to it.

> This internal merging of the sign and the tool that found a material symbolic expression in the primitive digging stick indicates how early the sign (and later his higher form the word) begins to participate in man's operation of using tools and to fulfill an incomparable, unique, functional role in the general structure of these operations which are the very beginning of the development of human work. Ibidem.

Although one should remark again a radical difference, the stick used by the monkey and a stick used by a man differs although they are undoubtedly connected genetically. At this end Vygotsky recalls Köhler's considerations on the subject by which men provide themselves with a tool in advance, without the immediate intention of digging,

[98] The collected works of L. S. Vygotsky, Vol. 6 Scientific legacy, Kluwer, New York, 1999.

leading to conceiving a proper “beginning of culture”99.

> But instead of a metaphysical basis for this delimitation, prompted by our studies, we propose a historical basis, which fully agrees with the facts established by Kohler regarding the behavior of the chimpanzee. Thus, two types of activity which the psychologist must distinguish are the behavior of the animal and the behavior of a man: activity that is the product of biological evolution and activity that arises in the process of the historical development of man. Vygotsky (1999), p. 64.

In this sense life over time, cultural developments, working activities, everything that distinguishes man from animal in the psychological sphere is strictly connected in Vygotsky’s opinion to the *parallel*, and we may add *interactive*, development of a man on himself with the mastery of external nature.

The discussion leads to the consideration of voluntary and non-voluntary action which had been a theme of arguing between Kohler and Koffka and an entire theme on philosophical and psychological questioning till nowadays with recent neuroscience researches but that would bring us very further the limits of our discussion100. Anyhow we should leave with Vygotsky’s note on the subject who quotes Engels:

“Work created man himself” (Marx K., Engels F., *Works*, Vol. 20, p. 486).

On these lines stands also the consideration of basal and higher activities of cognition. We should very briefly and from a very general standpoint remark that there are two principal points of view on the question: one that professes a clear demarcation between basal and higher functions of the brain, and which, particularly, as we have seen, consider the brain result of dissociated elementary parts that get together without essential modifications, and one which puts in emphasis more the continuity between elementary and higher forms of cognition.

---

[99] Köhler’s first research text about apes is *Intelligenzenprüfungen an Anthropoiden*, published in 1917, the English version, *The Mentality of Apes* was published in 1926, Harcourt, Brace & Company, Inc., New York.

[100] In neuroscience field see for instance the distinction between action and movement in Rizzolatti, Sinigaglia, 2006.

Traditionally the power of word has been elected as the point of demarcation, with the slogan: “In the beginning was the word”.
Vygotsky, who we have seen puts a clear difference between animal and human ways of using tools, nonetheless concerning the power of the word rather prefers to emphasize that of action, so the slogan would result: “in the beginning was the action”. Yet again the peculiar move that we learn from Vygotsky is the approach, or the focus, or the methodology, thus not concerning the *what* but the *how*. In fact, as we said a peculiarity of *GT* was the interaction-approach intrinsic also to methodology and to theorizing. We put in evidence the power of the interaction at work, in the internal organizational process, thus as a proper activity, rather than subject to an external law or criterion. Here Vygotsky made possible undergoing onto another distinction concerning the interaction between word and action, which one should add, stands as the most characterizing process of human beings condition. On one side criticizing the logical approach by which speech and action are logically parallel and independent. According to this position one supports anti-genetic and metaphysical position which rejects development and which establishes the “rank of an eternal law of nature ignoring the changeability of functional systemic connections and interactions” (Vygotsky, 1999, p. 66). The most common errors stand inside the crime scene, or in the particulars, leading to the fact that the problems one has tried to leave out of the door are inevitably popping up from the window. In fact, here is the keen attention revealed by Vygotsky, “the contradiction between theory and facts” (p. 66) one could maintain this anti-metaphysical point of view, but then consider the relation of words and acts statically, as a thing and not as a process, as an eternal and unchangeable. In other words loosing the dynamics, the interaction-twist.

> In truth, the dialectical character of development of functional systems cannot be adequately reflected in any one constructive logical scheme of relation of concepts [...] since neither the one nor the other considers the mo of concepts and the processes that stands behind them, the changeability of the dynamics and dialectics of development. Vygotsky (1999), p. 66.

We will see in chapter three a proposal of a logic that would provide what here seems to be absent, the twist of interaction: the consideration of an interactive network of proofs and their specific "history" in the meaning of their "procedural" interchange and as something that is used, that is not conceived by means of an essential character, rather by existentialist one.
So to sum up we can remark the interaction approach which should connect, by the book, not only facts, experiences, stimuli but also these very data and observations with the theory.

> Whoever pays no attention to this inevitably perceives the psychological nature of both speech and action in a false light since the source of their change lies in their functional merging. Whoever ignores this basic fact and tries to present speech and action as two parallels that never intersect in order to preserve the purity of a classification scheme necessarily limits the true amplitude of the one and the other since the amplitude of the content lies primarily in the connection between the one concept and the other. Vygotsky (1999), p. 67.

11.

One can underline then that a first topic of Vygotskyan theorization is braking up with the empiric-positivist conception according to which knowledge mirrors reality.

> La realtà non è qualcosa di dato, di esistente di per sé, che la scienza scopre in un percorso di progressiva approssimazione, ma è ciò che una cultura, una società, una comunità scientifica ritiene sia tale: la realtà esiste in quanto pensata, cotruita da individui e da gruppi sociali nel proprio contesto storicamente e socialmente determinato. Mecacci, 1999, p. 77).

As a consequence of this "de-cognitivization" of reality, or "de-essentialization", scientific concepts are not fix entities and are historical products too. Furthermore these ideas, also with respect to their evolution, are not established by falsifying criteria[101]. On the contrary, they rely on social factors, thus their evolution follows the peculiar instability or the stratification process of human culture that we have mentioned before. At a certain time these notions/theories can be reckoned, then disavowed for contextual and extra contextual reasons (as economical, politics interests, cultural domination, ways of diffusion and so on), then may be rediscovered again.

The result of these assumptions is that scientific research is a form of social-action, which is a pivotal point in Vygotskyan thought[102]. When a theory, or an analysis describes and/or explains the world it enables at the same time people activities towards certain directions, canalizing some behaviors, or rather imposing and forbidding other behaviors. This side of the question has been particularly put in evidence by French epistemology of past years (Canguilhem, 1966; Foucault, 1966).

We cannot open here this discussion on French and Russian critics about culture and *episteme*[103], anyhow we we should remark that Vygotskyan analysis is especially focused on the psychological notion of process-activity. In fact, a point that Mecacci puts in light is that in Vygotsky's opinion not only psychological concepts are changing through times, but also human psychic functions. More properly the Russian psychologist proposes an historical-cultural theory of psychic by which there is a remarkable crossing interaction, to the limit of a carnal imprint between practices, bodies, functions, matters, concepts and knowledges. As we have try to hint with the title of this chapter, "Through matters and times".

Vygotsky puts in evidence that the historical evolutions happen on two levels, a material and a conceptual one: for instance the mind of an ancient Egyptian is different from an inhabitant of the same Egypt in year two thousand. Let's specify better what Vygotsky means. He does not refer to the phylogenetic evolution of the brain, rather on its

[101] See for instance Popper, 1972.

[102] On the argument about science as an action, a powerful activity see also Oppenheimer, cit.

[103] See an interesting review in Wertsch J.V. (1998), *Mind as action*, Oxford University Press, New York.

functioning at the level of mental procedures.

As we have seen, the notion of *tool* is pivotal in this theory. Humans adopt tools to extend their brain, working to get always a "further-brain", if one allows us this expression. One of the most common instantiation of how a tool works is for instance the writing ability. Through life we gain a different functional organization of the mind by means of our capacity of writing, which was not included in our tool-kit when we were born. The metaphor of the educational process that Vygotsky criticizes is that of a plant that one "just need to water". We should be clear on this. If we attentively read what said above about the historical and social determination of the minds we should have already concluded that our functional system, or the functioning of the mind, depends on external facts in an interactive way, thus external to the very material structure, the brain: "Esso si realizza solo e se la cultura organizza le funzioni inferiori in questa funzione inferiore" (Ibid., p. 79).

As Mecacci (1999) underlines there are many other psychologists that have recalled the notion of tool as Bruner with "prosthesis" and Norman with "cognitive artifact". But the main distinction is that the Vygotskyan tool does not only help our mind but it modifies it too.

> La mente umana per Vygotsky è umana in quanto è una mente che si è funzionalmente riorganizzata e continua a riorganizzarsi poiché è mediata dalla tecnologia: è in breve una mente tecnologica (ivi, p. 80).

It is very interesting, thus, underlining that all the human productions (in arts, manufactures, literature, ... but also thoughts, concepts and so on) are not only externalized objects, but they are mostly *internalized*, they are tools of the internal process of the mind. In other words, all these practices-processes are an external medium that is *incorporated* in mental structure as an essential component. This has a particular interest for us not only because it has many points in common with nowadays conceptions of the minds (Berthoz, 1997; Rizzolatti, Craighero, 2004), as we will see more in detail, but also because it is very consonant with our personal opinion about the evolution of the notion of interaction.

To give a recent example of this historical conception of the mind we can note a passage by Michel Pastoureau that is a French specialist in Medieval history, specialized on the symbolism of colors[104]. He underlines how the occidental history of colors is marked in the beginning by red, white and black.

> È quanto è accaduto nelle società occidentali: la triade primitiva bianco-rosso-nero ha esercitato il predominio dalla protostoria fino al basso Medioevo; poi si è operata la promozione di altri tre colori. Tale mutamento è avvenuto tra il 1100 e il 1300. Da allora le cose non sono minimamente cambiate. (Pastoureau, 2010).

It is interesting though, that Pastoureau underlines that this is our peculiar history. In other cultures the story changes.

> Altrove la storia cromatica si è spesso sviluppata seguendo altri ritmi, altri schemi, altre variabili. Alcune culture non isolano le unità di colore come in Occidente, ma poggiano su parametric che sono loro propri. In Africa nera, per esempio, fino a poco tempo fa, l'essenziale non era sapere se un colore era rosso, verde, giallo o blu, ma sapere se era secco o umido, liscio o rugoso, morbido o duro, sordo o sonoro. (Pastoureau, 2010).

We may say, according to *GT* that there are particular structures of organization, which are unities of analysis, but contrary to *GT* and in accord with Vygotsky and Pastoureau we have to remark that these unities are not *universal*, rather historical and socially determined. We said that Köhler points out a reflection that he leaves opened, as a theme for future research about biological temporal perception functioning. This conception puts into light the importance in biology of the dimension of time, which is strongly linked with dynamics, rhythm, irreversible character of individual's life, as we will develop in next section.

11.

[104] *Les couleurs de nos souvenirs*, Seuil, Paris, 2010.

We want to conclude this part on the psychological sight concerning interaction with a metaphor by William James.

> Noi tendiamo a scindere in due grandi metà l'intero universo; e per ciascuno di noi l'interesse tende a convergere su una sola delle due metà; ma tutti tracciamo la linea di divisione in punti diversi. James (1890)

What James says above may beautifully apply to the history of psychology itself. Following Mecacci (1999) one may distinguish two main sections in psychology theorization that scholars call differently according to their personal standpoint: two main methods and two different minds105, dualistic prescriptions106, phases107, programs of research108, tradition of research109, components110, domains111, schools112, or modalities of thought113.

In more philosophical terms, these two standpoints can be summed up by the conception of a subjective and universal mind opposed to an historical, social and discursive mind (Mecacci, 1999). Both minds can be studied via basal processes experiments or rather by means of an observation of developmental and social behaviors. The result is an epistemological evolutionary process itself, as we have seen already in physics and as we will see in biology; a mosaic of interpretations in which at a specific time different configurations are possible: one theory emerges and dominates over another, or rather the two theories divide into sub-unities some of which may connect together and later on oppose or rather only one of the two theories dominates and many years afterwards the other is discovered to be valid too and so on.

We are clearly not in the position here to take into account the wonderful history of the evolution of these standpoints[114]. Nonetheless we should

105 (Wundt, 1896; Spranger, 1926)
106 (Watson, 1967)
107 (Hebb, 1960)
108 (Lakatos, 1970)
109 (Laudan, 1977)
110 (Bruner, 1990)
111 (Leahey, 1992)
112 (Ardila, 1992)
113 (Mecacci, 1999)
114 See Dazzi, Mecacci (1982).

sketch out some major elements of this story which are useful for our discussion on the concept of interaction. In fact, a key point that one finds so clearly diffused in the history of psychology, for over a hundred years, is the topic on the family area of the concept of interaction; even if its proper employment as a term, or as an instrument of research or as an approach has had an increment only more recently, as we have mentioned in the introduction. But, then, it is not so difficult to propose also for the main topic of interaction the same metaphor that James enlightened in the quotation above.

Recalling the ten oppositions that we have underlined during our investigations we would see exactly how James' metaphor beautifully applies. "We are inclined to devise in two halves the entire universe; and for anyone the interest tends to converge only in one half of it, but we trace this division line in different points". So we see what happens when focusing on the oppositions we have found till now:

- determinism vs indeterminism
- corpuscular vs undulatory
- atomism vs holistic
- mechanism vs vitalism
- physical vs biological
- analytical vs synthetic
- objective vs subjective
- elementariness vs gestalt
- quantity vs quality
- universal vs historical

The line clearly separates two different halves of the universe, but depending from the point of view this separation is applied to thought, matter, approaches, modality, methodology and so on. And thus again, looking through this polarized world the antinomian conception of the notion of interaction that we have enlightened does not seem to come out of the blue. Depending from the side one tends to be more inclined to, one would chose for a deterministic/analytical/universal standpoint or rather for a multi-factorial/synthetic/historical point of view. It seems

quite evident that this polarized horizon that I am proposing is itself a gestalt, an organized structure, as result of human process of ideation; thus it is an horizon provided of a ground in which emerges the figure, or in other words the two oppositions are mutually exclusive but mutually living one over the other.
Anyhow, this, as James explains very well, is the result of a choice and according to Vygotsky's image of "research as social-action", thus always historical and contingent, I could add that this is always the challenge of a choice, and at the same time the claiming of it, as we will particularly see also in next chapter. I think that I have explicitly let you glimpsing for which side of the coin I do feel more inclined and I propose you to trace the line, look and make your choice too.

Chapter two

Biology on interaction: variability, constraints and polarity

I. A logic for biology?

1.

In *Nature* “Horizons” (24 July 2008) Paul Nurse asks himself how focusing on “information flow” could help in better understanding cells’ and organisms’ processes. Biology, he says, stands at an interesting juncture. At one side it has known an increasing period of research in the last decades. The greatest advances of which have been made mostly thanks to the improvement of molecular biology techniques. The main idea used as the theoretical basis of these researches is that

> Gene is the fundamental unit of biological information and that chemistry provides effective mechanistic explanations of biological processes. Nurse (2008), p. 424.

Nonetheless, though such an increasing ability in analyzing living processes has been very useful –and not only for the comprehension of cells and organisms, but also for a better knowledge of human diseases– on the opposite side, we can affirm with Nurse that a “comprehensive understanding of many higher level biological phenomena remains elusive” (ibid.). Moreover this fact is true at many different levels. For instance talking about cell life, phenomena such as general cellular homeostasis, maintenance of cell integrity, generation of spatial-temporal order, inter and intracellular signaling, cell “memory” and cells reproduction are all still not clear. At a higher level, we find the same kind of difficulty in describing tissues, organs and organisms' organization in processes such as embryogenesis, neural development, immune system, and all diseases, such as the explanation of cancer. Furthermore, in fact, the bio-medical community adds a "sense of unease" to this uncertainty, as it seems that human disease researches are developing far too slowly with regards to society's need. As a matter of fact one may explain that the main cause of this sense of unease should be attributed to premature expectations. In fact there has been a far too common sense of confidence in biologic research rapid possibilities of comprehending living beings processes. In other terms, we can say that thanks to the promising results of research programs in the last decades we have been led "to underestimate the complexity of living organisms" (ibid.).

Nurse proposes a theoretical point of view to look at for trying to give an answer to this difficulty in having a *comprehensive understanding* of many higher level biological phenomena:

> There should be a concerted programme to investigate this, which will require both the development of the *appropriate languages* to describe *information processing* in biological systems and the generation of more effective methods to *translate* biochemical descriptions into the functioning of the logic circuits that underpin biological phenomena (ibid.).

Despite the conciliating and synthetic approach, we have to be radical in this, the main concept we are suggested to refer to is *information*, even if it is considered from an extensive point of view that enlightens the importance of complexity and interaction, both primary elements for describing living beings. The problem of information in biology is certainly not new and since many years is at the center of a debate (Atlan, 1999; Godfrey-Smith, 2007; Rosemberg, 2009) into which we rather do not want to enter directly. But for many analogies with our topic on interaction, we feel to briefly put into light some elements discussed by Longo (2009, 2010).

In the biological communication-mechanism there is always emergence of "information" (Ricard, 2008) as for all the main biological processes: the communication happens by means of a network in which the organization is emerging spontaneously. And, to this, one should add all the contextual happenings such as pressure, temperature, pH, all participating for example to ontogenesis' development, and moreover the *milieu* environmental which participates to morphogenesis. When one looks at Shannon's Theory or to computer science's models it does not have any sense that a source of information or a machine would be subject to such an amount of influences/interferences/interactions bringing the system to possible substantial collateral effects.

> C'est-à dire, le contexte non-digital n'affecte pas l'information transmise ou élaboré (et tout est mise en place parce que soit ainsi) ou, au plus, il peut detruire toute ou partie di dite information. Et cela est formalize par un principe fondamental, le principe d'entropie à la Shannon: l'information, peut augmenter seulement si on lui fourni de l'information, sinon, en general elle baisse. (Longo, "Au sujet du livre *Tout et ses parties*, par Jacques Ricard", 2009).

We can underline two different questions: on one side this inter-correlation and dependency from the environment vs the non subordination of the digital to the non-digital context, on the other side one should add that the proper determination of every discrete structure is Laplacian. From a traditional point of view information theory is not based on probability and randomness analysis, even if Shannon seldom employs this tool. Strictly speaking the probabilistic analysis is to be found in physics, and in particular associated to a theory of measure. Is in this context that according to Longo one could attempt a parallel with the biological field, and in particular to the analysis of complexity, as result of living beings' organization, by means of metabolic networks (Bailly, Longo, 2008).

> Le défie est certainement important et nouveau, car il s'agit de se donner de critères quantitatifs pour comparer (mesurer) l'organisation, en tant que mélange complexe d'ordre et de desordre, integration et differentiation, niveaux d'organisation différents mais causalement correlés... (Longo, 2009).

This said, we can recognize in this idea of communication/interaction as information, as a quantity of "something" that produces communication/processes/information itself the first occurrence of the concept of interaction that we have encountered: deterministic/elementariness/analytical. Not to mention the fact that as an explanation it is not very useful to say that something produces information by means of information itself, acquired by information, etc. This may recall the vicious circle produced by the unincorporated representation of the man-machine to which we have made reference, in which the machine that at first is conceived by the Universal Subject in the end turns out to be the model for the conception of the Universal Subject itself.

We have already remarked the importance of discussing the established mechanistic input-output model of reference concerning individuals' processes and we have hint how an historic-functional-gestaltic point of view may better describe living beings' dynamics. In this chapter we are trying to better comprehending why. Moreover we can straightly correlate this analytical approach with two other elements noticed previously:

- the idea of gene as the unit of biological information
- the gap between general expectations in explaining living processes and the underestimation of their complexity

Anyhow, from what have read by now is not possible to judge if Nurse refers to a mechanistic model or to the "input-output" criterion to describe organisms' processes when he speaks of this "information flow".

But a first difficulty we see is keeping together the information as the main model, thus as we said determined and reiterative, with the necessity to find, as Nurse requires, some "*appropriate languages*" to describe living processes, which are more in the key of variability and evolution. In this work, just as an exercise, we could propose to start to substitute every time that the word *information* appears, which the author uses frequently, with the term *interaction*.

2.

It is very well pointed out by Nurse that in the last years of biological researches the emphasis accorded to the description of the components and their functioning has overcome its complementary approach; that is a comprehensive synthesis of all the mechanisms by which living beings gather, process, metabolize, memorize and use the possibilities they possess. This can be seen, for instance, in the example of the interaction-loop between DNA, protein and metabolites in the lac operon, a set of nucleotides that regulates the metabolism of lactose. We understand the functioning only when we look to a complete cycle: half of the path is the transcription mechanism (*positive*), which determines the lactose production. The complementary side is the *negative* feedback loop that processes the signals of the level of lactose in the environment to regulate the rate of lac operon transcription. As an example the lac operon can be used to represent the need of a better understanding of interactions field or what Nurse calls the "information flow" that cannot evidently be confined to the linear scheme of the transmission "from gene to protein". Nurse's idea is that the information flow should be analyzed in analogy with a more "abstract" and dynamic logic circuit that can enable it. Let us see how.

First of all, the cell is the main unit of reference for the model, as it is the simplest entity that shows complex biological phenomena. The program is made of three different paths: (1) logic, (2) biologic and (3) their synthesis.

Phase (1) focuses in enlightening some primary elements or logic "modules". As a simple remark, but in a sense our work might be not more than finding some connections and clarifications, we would be prudent also with this use of "module" because its analogy with some logical approaches and metaphors, for instance Fodor's modular conception of the brain (Fodor, 1985). In particular, the idea of rigid and close modules as black boxes that treat information is probably too limited to represent the continuous interplay and feedback loops proper to biologic processes. As we have put in evidence with *GT*'s concept of organizational process, a conception that looks only at inputs and outputs, bypassing the main processes generator mechanism, in our opinion leaves unattended two facts:

- the recognition of how functions are instantiated
- the rebound of the outputs into the generation mechanism itself.

The linear description of modules dependency is scarcely tuned with the basic and over diffused biologic principle of interaction. At first, Fodor's modular model of consciousness was theoretically used in fact to oppose to the interrelation of processes[115].

> The Modularity of Mind proposes an alternative to the "New Look" or "interactionist" view of cognitive architecture that has dominated several decades of cognitive science. Whereas interactionism stresses the continuity of perceptual and cognitive processes, modularity theory argues for their distinctness. It is argued, in particular, that the apparent plausibility of New Look theorizing derives from the failure to distinguish between the (correct) claim that perceptual processes are inferential and the (dubious) claim that they are unencapsidated, that is, that they are arbitrarily sensitive to the organism's beliefs and desires. In fact, according to modularity theory, perceptual processes are computationally isolated from much of the background knowledge to which cognitive processes have access. The postulation of autonomous, domain-specific psychological mechanisms underlying perceptual integration connects modularity theory with the tradition of faculty psychology. Fodor J., (1985), p. 1.

Without entering in such a debate, it should be enough clear that our position supports on the contrary an interactionist-historical approach to mind constructions and also to the description of evolutionary constraints in life matters. Therefore we think that for getting the "logic tool kit" that Nurse propose, as expressive as possible to represent interactions flow of biologic processes we should probably make a new start, and for instance do not use a modular logic approach. For instance the concept of module that Fodor used to conceive a simplified model of

---

[115] For a distinction of intentional and computational modularity and for an interesting discussion on diachronic modular theory vs evolutionary theory-theory see Segal G., "The modularity of theory of mind", p. 141-157, in Carruthers P., Smith P.-K., *Theories of theory of mind*, Cambridge University Press, 1996.

the most difficult, ambiguous and indefinable process such as consciousness is may not be the proper tool for describing living beings' functioning. The aim is different and the object is different: we are not treating reasoning, subtle thought and consciousness, but as a start, biochemical, signaling and circuiting mechanisms (which of course are underpinnings of every consciousness, but this stays at another level of discussion!). Moreover, the principal purpose is giving more expression to a quite simple mechanism for understanding the logic possibilities it underpins.

We would say, then, that a more dynamic approach might be guided by the natural logic of biologic organization itself rather than imposing to it a standard artifact module logic approach. In this sense, though self evident, we should remark again that every fact is an artifact coming from our gnoseological approach in describing and understanding phenomena themselves. Or remembering Vygotsky it is a tool for our own mastery. So, what I want to enlighten here in the opposition of artifact and natural can be more precisely understood by the opposition of linear and dynamic: w need to focus on an expressive model to represent living beings mechanisms the nature of which, as we have seen, does not seem so linear at all.

Anyhow, having expressed our opinion, we may follow Nurse's point of view, by which logic modules represent minimal functions allowed in the system, as for instance negative feedback loops (which normally operate in a homeostatic manner) and positive feedback loop (which can generate irreversible switch behavior between one state or another) and their interplay that can produce more complex outcomes as reversible toggle switches, timers and oscillators (see… Nature 2004). The analysis should foresee then outputs behavior, as considering response curves embedded in the modules (whether the curve is linear, hyperbolic, sigmoid…).

The important characteristic to put in evidence is the module functioning as double memory storage: it can provide for short term memory device (for instance G protein in GTP-bound state) and long-term memory device (for instance DNA replication). All these mechanisms can be considered as the "logic tool-kit" proper to cells life (p. 425). The logic

tool-kit then can be seen in analogy with an electronic circuit that uses symbols to define electronic components nature and functions, which allow the "information flow". In the very case of cell, we would need as "information flow", instead of defined electric potential, a biochemical description of molecular components interactions. What makes it hard, as we have already had occasion to notice, is complexity arisen by the presence of many multi-factorial processes all around the interactions.
One way for going beyond this problem suggested by Nurse is searching a sort of boundary:

> If constraints exist as to what sorts of modules and linkages can generate effective and robust behaviors, then fewer possibilities will need to be considered (*ibid.* our italic).

A first comment is that the problem raised by a claim of complexity has always been attempted by making a shortage of complexity itself, thus "reducing" the measure of the problem. And as we have seen this very procedure doesn't properly allow a generalization of the reduced model into a theory. Because as Oppenheimer, *GT* and Vygotsky remarked, the problem is in the interaction itself, it arises at the level of the organization itself, thus should be considered at this level of phenomenality.
We have to add to the list of the two opened problems mentioned above (1. gene as the unit of biological information and common 2. "input-output" protocols to describe information flow vs. organisms' complexity) also this last one:

- the reduction of possibilities that we have related to the concepts of interference/measure/constraints.

So, resuming, the main problem of this phase (1) (logic) is yet to reduce variability to fewer possibilities. But we need to add that the very comprehension of the term "fewer" is important and meaningful. In fact, in our opinion in this reduction is not so evident what we may call "the passage from quantity to quality" as for instance it has well pointed out by the "*sorites* paradox" by Eubulides of Megara: what makes possible passing from unity, to an amount? If I have a pile of sands and I start to remove some sand grain by grain, which is the limit, the one unit of sand, that make evident the passage from a pile of sand to a grain?

3.

Coming back to Nurse's proposal, phase (1) closes when one has been able to recognize some modules that are operational in a process and describe how they are linked into circuits. In fact at this point one could try to describe the "information flow" and its main processes:

9. how information is gathered from various sources (environment, other cells, memory devices);
10. how it is integrated and processed;
11. whether it is used, rejected or stored for later use.

We comprehend that Nurse's idea is making a plan as general as possible for describing in general and thus at many different levels a sort of general functioning of living beings, which should undergo onto the general name of "information flow". In relation to that, a crucial point is trying to establish an appropriate *method* and also a *language* for describing this process. This language should be sufficiently expressive, but either simplified because it needs to be used as dialogue vocabulary, so should be comprehensible by crossed fields of researchers, such as biologists of different areas and computer scientist.

Here starts the second phase (2) which should bring to synthesize the "logic tool-kit" with biological data, which primarily requires simplifying the analysis of the cellular biochemistry as to link it with logic modules. Some examples are interaction trap procedures (two-hybrid methods, protein purification followed by mass spectrometry), but also the systematic cataloging of the position of fluorescent tagged proteins, as to identify specific proteins inter-relations and how they might change over time. In the end of this one should try to figure it out a spatial-temporal description that would allow limiting the analysis only to specific restricted possibilities of these domains. This phase already seems difficult but the next step (3), the proper synthesis, is even more difficult as it requires mapping the molecular interactions and the biochemical functions onto the logic modules selected before, putting together the cellular chemistry tool-kit with the logic tool-kit.

> The success of this mapping will depend on whether there are sufficient regularities between specific logic modules and specific interacting molecules, at least at some level of probability. Ivi, p. 425.

Here there are two main possibilities that Nurse points out in a very acute manner. On one side, if natural selection has recruited very many different components from chemical domain to generate logic circuits outcomes there might be not such a restriction of random possibilities; which would be a pessimistic perspective for research aim (but we could add may be not for other meanings). On the other side, however, considering presently available data, such as the use of nucleic acids for information transmission and storage or as the common use of protein kinases and phosphatases acting agonistically as switches, there might be sufficient regularities to make this step possible; thus offering optimistic view to research.
As normative science procedure protocol suggests, then, getting to know more and more about molecules interactions within logic modules, we could start to generalize and be "less prudent in considering the description of processes details" (Ivi). As, for instance, if we often find special linkage or associations between molecules and modules it would be possible to "predict some behaviors" (Ivi), without having to accomplish precise measurement of the variables involved.

> Simply knowing which molecular components are present and how they are linked together might be sufficient to speculate about which logic module is in operation. If this is the case, then the module can be considered as a black box and it might be necessary to concentrate only in vivo measurements of key inputs into and outputs from the black box to confirm that the logic module is behaving in the expected manner. Ibid.

At this point we can start to make some more comprehensive considerations. This three phases program is based on an approach that harmonizes two main aspects. On one side this analysis would allow a restriction of variables and random productions considering some of the specific interactions as objective, thus reiterating and predictable. While on the other side, it proposes a definition of some fixed logic tools that should be valid generally for some biological processes. The main difficulty of which we should be careful in this approach is that logic and biology domain should not tend to collapse one onto the other. The expressive power of such an operation is respected till the analysis preserved the dynamics between biology and logic domains. And not determining *a priori* some rigid logic tool-kits. Life variability, in fact, is till now known as quite randomly operating: epigenetics mechanisms, evolution through "punctuated equilibria" (Eldridge, Gould, 1972), DNA as a random generator of proteins (Kupiec, 2009), ecosystem and environmental standpoints (cfr. System Biology approaches e.g. Boogered, Bruggeman, 2007). An important element, hence, is taking into account this variability in itself as a main element when attempting to describe living beings' phenomenality. At this end an interesting challenge would be keep creating a feedback between logic and biologic pathways in analogy with environmental and epigenetic influences at the basis of every natural process.

4.

Moving forward we should see how this program would work in practice. In Nurse's opinion a first step is identifying higher-level cellular phenomena. Some examples are chemiotaxis, signaling, mating and some aspects of cellular reproduction. A possible approach could use genetics and genome-wide deletion collections to identify all the possible genes involved; then bio-informatics software would process these data to make them match with specific biochemical and molecular functions.

Using interaction trap and the spatial-temporal cellular domain database described above, we should be able then to determine which molecules interact one with the other and how they connect together. Next step would use this very same database to predict the probability that a specific logic tool-kit has to be linked with a peculiar chemical process. At last one should be able to determine a *complete circuit of modules* the output of which could be translated into a "narrative of information flow to describe how cellular phenomenon works" (Ivi, p. 425-6).

At this end, Nurse makes in our opinion an observation that encloses an implicit and not questioned assumption. He says that as modules are "analogues" or "working as" circuits, which are combined into networks, is possible to *understand modules functioning by looking at how networks work*. He adds that networks functioning has been analyzed in many other "spheres of *human* activity", as transportation (flight routes) and it has been put in evidence that there are some "scale-free" networks, as they are much more connected with others and so they become pivotal connections[116]. Moreover it has been showed that the very basic interactions of genetic networks as protein-protein and transcription mechanism are scale-free too; probably as they are ancient in evolutionary terms (*Nature*, 2010). The question briefly is that at a certain level of evolution something has been selected and canalized and the system tends to preserve it as it is. But apparently from this standpoint for treating biological circuits by means of the study of the general characteristics which describe networks functioning we should be able to harmonize two antagonistic standpoints:

- One that is history dependent, in which we see the results and only and always the results. So, from this position we cannot generally establish how and why it has happened what has happened, such as, for instance, for the question of the origin of life. More in detail, from one side of the coin, in a specific time these results can be considered as stable, canalized, and we can treat them as robust and invariant (Rosenberg, 2009). But from the other side of the coin these very processes are matter for new canalizations and so on, thus always contingent and not predictable.
- The other is a context dependent point of view which should foresee the happening of live processes, which does not have an

[116] See Buiatti M. (2006), Correlation a' longue distance dans les series temporelles biologiques, The'se de doctorat, Paris VI.

historic perspective, thus does not consider processes as canalized, stratified, differentiated, compartmentalized, but which nonetheless should not prevent itself taking into account somehow that these processes are always subject to the variability twist proper to nature.

Resuming, here one is attempting to overlap logic networks on biological ones to the precise extent of foreseeing phenomena by means of the knowledge of a priori logic underpinnings. From whichever point of view we look at the question (1. the history dependent or 2. the context dependent) the evolutionary trait together with the expression of the interplay between variability and structural, phyletic and developmental constraints should not be downsized.

Another fundamental question, which instead Nurse puts in evidence, are the *physical* and *logical* differences in the nature of logical and biological systems: in biological ones only some networks are quite physically stable, while others (or also the same at different times) support transient biochemical reactions (which is probably the very characteristic type). From a logical point of view logical consequences vary between either negative or positive configurations. So trying to translate or connect logic networks with biological ones we need to explore more efficiently the possible representations of how hubs work in biological networks. In fact, another major difference is physical: the fluidity and the dynamic of living processes. Biological networks can reconnect and reassemble in different ways as to generate distinct paths with different outcomes. By means of redundancy and plasticity supplies, respectively, for instance, a different molecule can be linked into the network to do the same job of the molecule that has replaced and give the same outcome of the other; while on the contrary other particles can be interchanged and give birth to new connections. This pleiotropy feature means a same mechanism (biochemistry) that in different context gave rise to different functions (cell differentiation, proliferation, form and development, migration, apoptose; as well as the complex functioning of the interactions in the signaling pathways Artavanis-Tsakonas et. al., 2000; Fortini et. al. 2009). And one should mention also the factor that can be named “plasticity generator” which grants the fundamental trait of multiversity (apparently opposed characteristics can be found interplaying together in a same system) and the variability of living processes, also at the genes’ level.

> I generatori di plasticita’ in questo caso sono veramente molti a livello genetico ogni genoma di eucariote contiene sequenze dette “ipervariabili” che sono strutturate in modo tale da mutare con alta frequenza. Questo ad esempio e’ il caso dei geni per le immunoglobuline che sono essenzialmente gli stessi di generazione in generazione ma mutano con altissima frequenza durante la maturazione delle cellule preposte alla risposta immunitaria alle numerevoli aggressioni che subisce l’organismo. Buiatti (2008), p. 74.

If one trying to give a description as general as possible of living beings by means of the “information flow” protocol, leaves out from the plan this interaction, this dynamics continuously interplaying in biological matter, he/she may loose the chance to consider one of the most characteristic aspects of life.
At this end a question arises: how one could possibly represent this sort of variability proper to natural phenomena which at the same time allows two opposite phenomena such as dynamics and robustness? We will see in next section a critical attempt to discuss this question.
For instance, taking examples from neuroscience, on one side there are very specialized neurons , which are altogether in different networks but which *at the same time* keep their plasticity, as they are able to switch onto different networks and change the function to which they apply to. Or, further, think about the sense of identity, or “the self”, to which we have already made reference, which surprisingly is preserved through so many alterations (structural, chemical, metabolic, pharmacological...) during the course of one entire individual’s life. Moreover the discoveries of last decades are augmenting and never diminishing the assumption of more and more possible interactions to discover, thus, for instance, in complete contradiction with the assumption of one only program to fulfill basal and complex genetic mechanisms.

> Si puo’ dire, anzi, che se ne avesse uno solo sarebbe morto, e morte sono infatti tutte le macchine costruite loro si’, con un solo programma, dall’uomo. Anche l’antinomia genotipo-fenotipo quindi si risolve con il semplice concetto di interazione non additiva e si conferma che I limiti entro cui si muove ogni percorso (I vincoli) derivano dall’interazione (dal “riconoscimento”) fra segnali esterni e componenti dei sistemi viventi. Ed e’ ancora una volta l’interazione che spiega il fatto che I cambiamenti evolutivi non hanno sempre la stessa velocita’ come e’ stato dimostrato da Gould e Eldredge nel senso che ci possono essere periodi di cambiamento praticamente nullo e poi improvvise accelerazioni (I cosiddetti salti). Biuatti (2008), p. 74.

All these examples remind us of the importance of the interaction as a key to living beings’ life and evolution. The interactions at many different hierarchical levels (as we will see for instance later in the discussion of cell proliferation and neoplasia development) are a counterpart of life variability. And these very interactions are in part “linear”, but in part always very complex and irreducible. Underlying the polarity of the concept of interaction as an heuristic instrument for our acknowledgement of living beings’ phenomenality.

As Nurse remarks:

> The language used to properly represent biological networks will need to accommodate these variations in logic structures. (ibid., our italic).

But for the moment, as we have discussed, the language that has commonly been borrowed from computer science does not seem to be the most appropriate.

5.

Two other fundamental features for this practical phase according to Nurse’s standpoint would be temporal organization and dynamics, which are strictly related the one with the other. The traditional representation of cell signaling pathway – that is the integration of all the complex systems of communication intra and inter cells – has been presented as linear: an on-off mechanism[117]. A good metaphor for this mechanism is the railway signal “stop or go”. But we are becoming more and more aware that with such a linear metaphor we cannot go very far in comprehension of whatever phenomenon we observe in nature. Living beings are more complicated, and in particular some complexes emerging behaviors distinguish them. Whenever we try to give to a structure a characterization as linear as possible it seldom presents from another correlated point of view another aspect that exceeds that trait of simplification and linearity[118]. This polarity, as we have put in evidence is one of the main traits of the concept of interaction, which entails interplays but also interferences. In fact though data recordings are increasing this does not necessarily mean that they are all consistent, leading possibly to a unitary theory. This is also one of the reasons why science theories progress very slowly and unpredictably, as we have seen previously underlying the peculiar “resuming character” of scientific research. Think about the famous mirror neurons experiments that started nearly twenty years ago, there one can appreciate directly the impact of new researches for the theory building. In fact, recent studies have put in evidence the impossibility in considering one unique Mirror Neuron System, as it has been named originally, which would work as a definite network (Rizzolatti, Cattaneo, 2004); rather one prefers now to make reference to “mirroring mechanism” (Rizzolatti) or to its plural version, “mirroring mechanisms” (Gallese)[119].

A substitutive metaphor of “stop or go” railway signaling that Nurse proposes is the telegraph and Morse code[120]. Nurse employs it to suggest the analogy of the representation of cells signaling pathways with the possibility of transferring via Morse code the works of Shakespeare, which is quite a catching idea. The problem is that what I find catching is exactly in the opposite meaning of Nurse’s employment. In fact, while he seems to sustain a possible conversion of Shakespearian plays through

---

117 See in particular chapter 15 of Alberts B., Johnson A. Lewis J., Raff M., Roberts K., Walter P. (eds.) (2002), *Molecular Biology of the Cell*, Garland Science, New York.

118 See Artavanis Tsakonas, 2000; Gilbert, 2007; Lee, Jablonka, 1999;

119 Scientists’ presentation at “Institud Nicod conferences”, ENS, Paris, 2010.

120 For an historical-philosophical discussion about the metaphors of the brain see Debru, 2010.

Morse code, my standpoint on the contrary denies the possibility of getting the expressiveness of Shakespeare poetry via Morse code. And also concerning cells signaling pathways there are different selective unities, responding to different networks where networks mechanisms work in a highly complex and interactive way (Artavanis-Tsakonas et. al. 2000). Thus, again, completely opposite to linear-deterministic features: these units altogether are not in a linear continuity, the underpinnings do not resume the more global properties such as plasticity, or redundancy or the emergence of mechanisms that by now we cannot even be explain or imagine (Buiatti, 2008). This is the interesting fact of interaction[121]. Recalling the metaphor, what is communicated in Shakespeare's works is definitely "more" or "other" than the simple juxtaposition of the words the verses are composed by. Here again we are in the presence of a *Gestalt*, an organized structure, the properties of which should be observed as a and within the very process of organization itself as we said, in which emergent internal properties raise, and at the same time one should remember that talking about an interaction it is always subject to interference. Thus, talking about the parallel with the Morse code, from what said about the information one should remember nonetheless that

> L'apport, meme quantitative, d'un noeud à l'organisation d'un reseau doit etre mesuré par l'organisation intrinseque de ce noeud et par un terme qui mesure le niveau d'integration de ce noeud dans le reseau. Longo (2009).

Not talking about the role of the interpreter, of the audience of the Shakespearian play[122]. To put it better this mans that all the verses in their semantic *Gestalten are shared* between the author, the actor and the one who reads or listen to it. The interpreter-audience role, his resounding with words, with the author or with the actor cannot easily be removed or by-passed[123].

---

[121] Emergence properties and emergentism have been ascertained especially by Varela and Maturana's works *e.g.* Maturana H., Varela F. (1980).

[122] See all the important works about the open meaning of a script as an *unicum*, an event and the role of the interpreter for its plain communication (*e.g.* Eco, 1962).

[123] See for instance Black (1962) conception of metaphors as an activity that works on

There is also another important consideration concerning the meaning, the expression and the reception of a *Gestalt* that we have already mentioned: the contrast, the polarity and the duration, its temporal character. As for instance *GT* has put in evidence the brightness of an object is perceived as changeable in relation to the darkness of the atmosphere. And it happens the same for acoustic matters, for instance we perceive a note after a silence with a higher impact than if we were immersed in chaos. There is a very beautiful page of Husserl's about the unity of meaning of a melody. He puts in evidence the importance of the retention of the unit of the (past) note into the new (present) representation of its sequent one, towards the protention (future) of the one that will follow (Husserl, 1929).
Going back to the proposal of the telegraph metaphor for representing the possible cell-signaling activity, we should say that yes as a *metaphor* may sound correct, but as an *example* it is absolutely inadequate for Shakespeare as for any basal redundancy and plasticity phenomenon which prevents cells "communication" pathways to be a one way linear functioning. We should add as a marginal note, and hinting a possible future line of research, that the whole idea of an identification between communication activities and cells processes should be considered more attentively[124].
We presume that in Nurse's description the expressiveness of the signaling process, thus redundancy and plasticity, for instance, would be guaranteed improving the power of the interactions of the basal code Morse. Staying at the metaphor level, in fact, it is true that "pulses of information sent along the telegraph generate a code for letters and as a consequence sentences can be communicated" (ivi p. 426), but out of the metaphor: to which code are we making reference?
The metaphor of the "code" has already had its most famous employment in the central dogma paradigm (1958), and nowadays this metaphor could be dismissed (*e.g.* Fox Keller, 2000; Atlan, 1999; Kupiec, Sonigo,

the assumption that the two speakers share the interpretation of the metaphor.

[124] See for instance Witzany's works all based on this assumption, or see (Alberts et. al., 2002, cit.)the title of chapter 15 is "Cell Communication".

2000)[125]. Talking at an epistemological level it is important then to propose some different metaphors or pivot concepts, as for instance those of dynamics or interaction which should provide more intelligibility to phenomena. They should not, on the contrary, become objects-principles themselves in a reification process that in the end leads to lose their primitive character of explanation, as it has happened for the metaphor of the genetic code. For instance by means of Nurse's proposal in the end we are implicitly suggested to think that:

- there is such a code, even if so complex that we don't grab it (so we can ad hoc add some dynamic, interaction, random...);
- there are also things such as information and modules even if we do not really now exactly what they are.

As Kupiec has very well put in evidence for the compartmental explication of cells differentiation (Kupiec, 2009) in these cases there is a sort of causal retroflection of the thought, or a *petitio principii*, because we assume as cause what we were looking for as the thing to explain. A common argument for cell differentiation is in fact spatial organization: inputs and outputs depending on spatial or context correlation. Especially taking as a model Alan Turing reaction-diffusion equations, one can say that logic circuits can induce spatial disposition and organization, as position-locating mechanisms during generation of cellular form. But how does in fact a cell form its form? Which are the basic constraints? As Kupiec explains the compartmentalization of the cell is now been used to express the causal determination of its differentiation. His position is that this is a misleading consequence of an "informational thought". Saying that the compartments of the cell are the reason for the differentiation corresponds to pose the effect before the cause, as cell in fact when compartmentalized is already formed. Compartments division does not explain why the same compartmental separation exists. One should add very briefly that generally every

[125] In fact, what do we really want to mean when we say that there is such a code, that it really exists? This may sound either very general, and so too general for the specific purpose of explanation, or only conceptual, say: we could state that there is something like "a code" to relate altogether all data, mechanisms, modules, hubs, circuits, networks, but the outrageous, irritating question is that we never find such a code!

biological transformation or process we observe is made by means of some pre-existing material determined through evolution. All novelty, initially are adds-on, which leads to permanent redundancy, then selection operates eliminating some of elements which have become the incompatibles (Longo, 2009).

Resuming we introduce the name or the concept of compartmentalization/code/information/module for searching an explanation of the functioning of cells basal mechanisms, but then we forget that making this we have not properly introduced an explanation, but just a name. Now, this is normal: recalling Feynman we proceed by approximation, but the problem then is that afterwards one notices a tendency in referring to these names and concepts such as things existing in themselves and no more as concepts; and thus one may even find some difficulties in discussing or proposing some conceptual adaptations of these concepts. Talking about the concept of interaction, for instance, we are trying to show how there is an history behind the employment of the concept, which is a part of the concept as much as its meaning; this story represents how the concept is alive in itself, thus is never something as it is, but on the contrary we register some "epistemological tendencies" or exaptations.

Concluding, Nurse made another statement the nature of which has to be made explicit.

> Lessons will also learned from higher levels of biological organization seen in communities of individuals, in ecological systems and during evolutionary change. The principles and rules that underpin how information is managed may share similarities at these different levels even though their elements are completely different. Studies at higher system levels are likely to inform those at the simpler level of the cell and viceversa. Nurse (2008), p. 425.

This sort of analogy is very catching and surely not new. Think about the systemic idea of life in Lovelock's *Gaia* theory (1979) to which we already made reference. First of all we have to notice and then do not forget that what Nurse propose is anyway based on analogy; secondarily we should analyze if the analogy is really possible and on the basis of which principles; thirdly we have to remember that we are moving at the epistemological level, the level proper of conceptual discussion.

We immediately glimpse a first nonsense which is scale shifting. Nurse in fact proposes to extend an explanation from the observation of higher level of biological processes (biological organization seen in communities of individuals, in ecological systems and during evolutionary change) into more basal levels of mechanisms. We have tried till now to put in evidence on the contrary the importance of defining a precise level of analysis with specific units of analysis, or *Gestalten, which are internal-organized structures.*

It is obvious but it is quite interesting that changing of scale is a well-known effect of interdependence between object and observer. So on one side we have to be aware of this very problem in general, but on the other we have also to consider the simple fact that what we may find correct at one scale level could be completely compromised by another standpoint or in another scale level[126].

So, evidently, looking at living beings we have to be aware of two ongoing scales at the same time:

- micro (interaction of complexes gene regulation...)
- macro (ecological, environmental and evolutionary context of development).

There is also another question that could be arisen which we could put under the name of "in vivo problem". Till now there are not as many in vivo data as those collected during their simulation or modeling. Nurse sustains with emphasis the need of an increasing amount of in vivo studies in both healthy and diseased state. To do this would be very well attended the possibility of higher sophisticated technology such as high-resolution sensitive imaging procedures to monitor bio-molecules in real time and space.

> This is the return to whole organism and human physiology that many have argued is long overdue, but with a renewed emphasis on the logic of

[126] For a more detailed discussion see next section and Bailly, Longo, 2010 in which a description of biolon and orgon was given as a possible conceptual explanation of different levels of organization.

> life and the management of information. (ibid.)

Even if we do not really fancy this metaphor of management for living (and in fact not simply "alive") processes and as we remarked before the informational metaphor should be regarded with suspicious, we can agree with the first intent of Nurse's proposal: one should return to the organism as a whole approach and the logic of life.

II. Variability vs invariance: biological vs physical conceptual oppositions

So far we have incorporated only our errors
and all of our consciousness refers to errors!
Frederich Nietzsche

1.

We have seen in the previous section the point of view about the relation between logic and biology of a geneticist and cell biologist who won a Nobel price in 2001. Now we have the curiosity to see the standpoint of a mathematician, an expert in computer science who became more and more interested in theoretical biology. At first we could think that he would have the temptation to reduce any living process to strings of digits and mechanical procedures. On the contrary, this chapter tries to put in evidence that another assumption is possible; which focus interaction between many different subjects such as biology, physics, medicine, neurophysiology and philosophical perspectives.

The main interest in this section of the chapter is analyzing some of the characteristics of the biological individual by means of conceptual and mathematical dualities: physics vs biology. Here we will see directly how our principal idea of interaction is directed in creating some possible folds of exchange between different subjects. A second aspect that emerges is that in this section we would continuously treating with polarities. Thus if we put it in a nutshell the question we would discuss is: could physics and biology reflect each other? Our answer, remembering the adequate level of approximation that Feynman prescribed to physical investigation, is positive, but with restrictions: the reflex is not pure and direct. In fact, when one tries to elaborate a mathematical theory apt to explain some aspects of biology, though starting from the clue of one and unique materiality, anyhow one becomes aware of some peculiarities. Especially during the elaboration of *theoretical extensions* of physics by new observables (Bailly and Longo, 2008: 2009), which gives an account in (possibly new) mathematical terms of *living beings' singularity*, some characteristic polarizations have been enlightened and verified. A key aspect of this approach is the discovery and the claim of a duality: a conceptual opposition between some theoretical aspects of the two disciplines. Figure 1. synthetically shows a representation of some conceptual dualities or, could we say borrowing the term from biology, a *crossing over* between physical and biological theories.

Let us add here because we frequently make reference to the employment of metaphors in science theory building that the theoretical notion of *conceptual opposition* is sharply distinguished from a metaphorical framework (Longo and Frezza, 2010), which is so common in biology. The strength of this methodological insight lies in a cross-logical procedure that clearly shows the *reversal* of parameters and relevant observables between physical theorization and biological theory building. Let us remark that in differentiating the theoretical frames of physics and biology we do not intend to make a material or *ontological* leap, but to underline a *methodological* difference between the two theoretical approaches. We are deeply convinced, is the only metaphysical assumption we make, that living beings are just bunches of molecules. The point is *which kind of theory* may help us to better understand and explain these physically "singular" bunches of molecules. Then, unification with existing or novel physical frames could possibly follow. See the current work in Quantum/Relativistic unification, by inventing radically new theories encompassing both current frames[127]. Moreover, and in contrast to the incompatibility of the Quantum Field w.r. to the Relativistic Field, our proposals for biology are based on *compatible extensions* of some *specific* physical theories. Of course, here our attempt is purely phenomenal and the absence of any reference to underpinning elementary physico-chemical processes corresponds to the historical practice of physics. In fact this discipline has been able to describe, in a very effective manner, Galilean inertia and the falling of bodies without any reference whatsoever to Democritus' atoms of which these bodies were composed even back in Galileo's time[128]. Later, Einstein unified inertia and gravitation, but still disregarding quanta, since, as of now, the gravitational (relativistic) and quantum fields are not yet unified, as we recalled. This kind of theory building made at different phenomenal levels has been a crucial part of the history of physics. The *unification* (Quantum/Relativistic) goes on by bringing two well constructed theories in relation under a novel perspective.

The diagram in figure 1. gives a synthetic representation of some conceptual dualities that have been individually discussed in detail (Bailly and Longo, 2008; 2009; 2010; Longo and Montévil, 2011):

---

127 For an analysis of recent quantum mechanics works see...

128 A fine analysis of Galilean discoveries and methods is in Einstein A., Infeld L. (1938).

PHYSICS	BIOLOGY
specific trajectories (geodetics) and **generic objects**	**generic trajectories** (possible/compatible with ecosystem) and **specific objects**
point-wise criticality	**extended criticality**
(Schrödinger) **energy** is an **operator** (*Hf*), **time is a parameter** $f(t,x)$	**energy** is a **parameter** (allometry), **time** is an **operator** (measured by entropy and anti-entropy production)
reversible time (or irreversible for degradation-simplified thermodynamics)	**double irreversibility of time** (thermodynamics and phenotypic complexity constitution)
randomness is **non deterministic** or deterministic non predictability **within a pre-given space phase**	**randomness** is **intrinsic indetermination** made by changing phase space (ontogenesis and phylogenesis)

Table 1. A possible theoretical differentiation between inert and living matter is described through conceptual dualities.

2.

To have a first idea of the functioning of this methodology which takes into account conceptual oppositions between physics and biology we could start with a simple remark. In physics *objects* are *generic*: they are invariants for experiments and theory (for instance, a Galilean weight or an electron as solution to Dirac's equation is equivalent to any other, it is generic), while *trajectories* are *specific*, as they are geodesics, an optimal path in the intended phase space. Geodetics are obtained as sums or integrals of gradients, sometimes highly complex ones, but always as "critical" paths, that is maxima or minima. Mathematically, they extremize a functional in some phase space (this is Lagrange vs Hamilton approach). Even in Quantum Mechanics a quanton will do the same not in an ordinary space-time but in a possibly infinite dimensional

Hilbert space: Schrödinger equation is derivable from the Hamiltonian and determines a quanton's evolution as the dynamics of a probability law. This is physics, from Newtonian mechanics to Schrödinger's equation. Antithetically to physics, in biology the *objects*, rather than trajectories, should be described as *specific*, rather than generic. This is due to the individual variability of living beings and their specific history, the analysis of which doesn't allow generalizations like in physics standard procedures. On the other hand, in biology: *trajectories* – phylogenetic, ontogenetic, or even those of actions – are *generic*; they are co-possible ones, i.e. they are the result of paths compatible with the co-constituted ecosystem and they do not follow optimality criteria. This is, for instance, one of the reasons for the explosion of the number of species, whom Darwinian natural selection theory refers to: trajectories are *explorations of compatible paths*. As a matter of fact, without genericity of routes there would be no Darwinian evolution (as life growth or explosion and, then, selection of the incompatible) and therefore no phylogenesis nor ontogenesis.

If one looks at Darwinian Evolution, the paths followed by phylogenesis are possible (or generic) ones, yet subjects to structural and phyletic "inertia" such as architectural and phyletic constraints (Gould and Lewontin, 1979). Ontogenesis goes along generic paths as well, the co-possible ones, yet with respect to more restrictive constraints, which are developmental, which are a subcategory of phyletic constraints. For example, in mammals, evidently the mother's womb canalizes embryogenesis "more restrictively" than an ecosystem may canalize the evolution of a species. There is a superposition and an entanglement of constraints as Gould and Lewontin have clearly enlightened in their distinction of architectural, phyletic and developmental constraints (Gagliasso, 2009).

In the lines of Evo-Devo theories, we can add that both phylogenesis and ontogenesis are forms of differently canalized variability. In fact, the core question of evolutionary developmental biology is *evolvability*, that explains how variation is generated through evolution and takes into account the pluralistic feature of organisms' developmental causes.

Development matters to evolutionary explanations because it structures the way in which variation is presented to natural selection. (Hendrikse *et al.*, 2007, p. 400).

If we move again into physics we find exactly the opposite situation: *generic trajectories*, whether they exist, are only rare exceptions, under determined constructions (for example Feynman path's integral[129]). And anyway, whenever the object would be put in the possibility to reiterate the path, it would statistically test every possibility. That's why an analysis of physical trajectories through criteria based on "selection" does not contribute to physical intelligibility: physical theories are much *stronger*, as they propose extrema of functionals (by energy conservation principles, say, or geodetics).

In order to better specify this crossed interaction between physical and biological principles, let's go back to the first part of Figure 1. If we look at it with this crossed standpoint: we notice a sort of double crosswise relation, as a chiasm.

PHYSICS	**BIOLOGY**
specific *trajectories* --------> (geodetics) **generic *objects*** -------->	**generic *trajectories*** (possible/compatible with ecosystem) **specific *objects***
***specific* trajectories** --------> (geodetics) ***generic* objects** -------->	***specific* objects** ***generic* trajectories** (possible/compatible with ecosystem)

Table 2. Trajectories and objects stand to specificity and genericity in a "crossed inverse proportionality" regarding biology vs physics.

[129] The path integral formulation of quantum mechanics is a description of quantum theory that generalizes the action principle of classical mechanics. It substitutes the classical notion of a single and unique trajectory for a system with a sum, or functional integral, over an infinity of possible trajectories to compute a quantum amplitude. The basic idea of the path integral formulation can be traced back to Dirac in his 1933 paper "The Lagrangian in Quantum Mechanics", *Physikalische Zeitschrift der Sowjetunion*, 3:64–72. Richard Feynman later after developed the complete method in 1948. See Feynman, R. P., Hibbs A. R. (1965), *Quantum Mechanics and Path Integrals*, New York, McGraw-Hill.

3.

Now we can recall what said previously about historical constructions and structuring of the mind, concept and theories. It is nevertheless useful in fact to insist on the idea that every theoretical-mathematical structuring is a human construction: science is a construction of objectivity (as spelled out at length in Bailly and Longo, 2010). There is always a friction of the physical-biological world with the cognitive practices and representations that lead to a theory. Briefly, one could focus on criteria for the construction of structures in mathematics and physics, which are distinguished from proof processes (and possibly empirical verification). Doing this one enlightens the relevancy of the constitution of mathematical concepts as derived from historical and cognitive experiences or "conceptual practices" (Longo, Viarouge, 2009). From this standpoint we can easily comprehend how foundational analysis of mathematics should be put aside to a parallel analysis of physics objects and percepts. Recalling Vygotskyan standpoint we can add that also physical and mathematical laws are not a priori or absolutes, such as entities in a separated set-theoretic ideal universe. On the contrary, with our cognitive practices and by a friction via our measure instruments, we are part and simultaneously we give rise to an active exploration of the world in a co-constituted sense, as we have see in detail in previous section and particularly by means of phenomenology standpoint.

We may now reverse in a Kantian way the perspective we have proposed in Figure 1: our representation of the crossed relation of the physical versus the biological world is not properly the way matter is, such as a thing in itself. Rather it is our method to norm and rule the matter proper to these different domains, inert and living matter, thus its *phenomenality*. As we said above it is not an *ontological*, but a *methodological* question. We have tried also to follow the characterization that *GT* gave to this question by means of intentionality:

a proper science of the qualitative aspects rather than a science only focused on the quantitative traits.

Starting with this methodological framework we may then try to make a step towards matter.

We propose to observe not objects and paths, but their relation, or interaction. We gain immediately a dynamics, a process. In fact, above in section 2. we have fixed as principal references trajectories and objects in physics and biology and we have evaluated their correlation with specificity and genericity. Then we have considered as main elements specificity and genericity in the crossover between physical versus biological objects and trajectories. If we look now at the *correlation* of the *object* with its *route*, we become aware that *in physics* they are described as *independent* the one from the other. A trajectory is defined independently from the different objects that pursue it and it is obtained by means of the physical law. This allows having *generic objects* with *specific trajectories*, which is our correspondence above in Figure 1. In biology is exactly this kind of correlation or law that is *not possible*: living beings are *never independent* from their paths. Each organism is the result of its own route and history.

With this crossover one becomes aware in a very immediate way of different physical vs biological principles. They operate in one and only materiality, which is differently organized and which offers two different phenomenalities:

- what is exactly the *fundamental principle* in the case of physics, the genericity of the object and thus the universality of the law, is *opposite* to the *primary criterion* in biology, the specificity of the individual;
- what is *not relevant* or without meaning in physics, as errors or history, becomes a *core principle* in biology, as we will see in sections 4. and 5. more in detail. We can argue that if one wants to express into physical terms the correlation between the object and the trajectory, the physical law is not straightforward suitable for biological domain;

- what is a *correlation* in physics becomes more properly an *interaction* in biology, where variability is one of the principal actor in all processes.

In general a law for objects and trajectories of one domain would not suite the other, but this very fact, at least, can be expressed by an opposition, as we are proposing. We claim that these conceptual oppositions may contribute to theory building in biology better than flat theoretical transfers. At the core of the theoretical proposals in the quoted Bailly-Longo's book and papers stands this chiasm between physics and biology as a methodological assumption. It is an epistemological attitude which may help avoiding a surreptitious determinism as well as teleological imposition from above that describes every objects as "made for" or "function of". We should add that this approach might guarantee also that the different standpoints do not collapse the one onto the other, which could be one of the most frequent risks as we have noticed in previous section concerning logic tool-kit and biological networks.

4.

At this point we can try to put all we have described till now in a more comprehensive frame. Two key features of living beings' paths can be resumed in dependency on history and on the traces of history as biological "memory". The historical-evolutionary and ontogenetic course codetermines the process of individualization of each living being, species...

From this standpoint we can introduce also a new element: how the role played by error and pathologies clearly separates a possible theory of living phenomena from any physical theory, where these two notions make no sense. In fact in physics trajectories never include errors, as they follow optimality (see next section). Genericity of trajectories, on the contrary, allows including pathologies in the analysis of living phenomena: pathology may be at the origin of new possible evolutionary paths. Similarly even an “error” within the process of learning, via *retention* (or memory, see next section), can precede a successful action, via *protention* (or anticipation, see next section) and so on. These notions, that are not proper to theories of the inert, based on specific and optimal trajectories, must be present in any theory of living phenomena, in particular when attempting to mathematize them. Their unification with the underpinnings molecular processes is a subsequent step: we stress that in order to “unify” is necessary to have at least two theories of different phenomenal levels to be unified.

We can say with a slogan that resume many of the characteristics that we have put into light till now such as interaction/interference/possibility/*Gestalt*/polarity/constraints/history and evolution that the core of living matter dynamics, at all levels, from evolution to human action, is *exploring possibilities*; something that doesn’t make sense in physics and that contributes to the difficulty in explaining physically living beings.

We want to enlighten this passage, because it gives a good general appreciation of living phenomena. We propose to describe living process as:

- *active* (protension)
- *responding* (to the environment and natural selection)
- but not *determined completely by a pre-given* set of known physical laws, since variability and evolvability exclude such a complete determination, as we are trying to show in this work and through the conceptual dualities hinted above (which suggest on the contrary a biological form of extended “determination”).

5.

For better clarifying this central idea of living processes as exploring possibilities and its consequences we can stop for a moment on one consideration: *a physical object never goes wrong*.

A falling stone or a river never takes the wrong path. By following local gradients, thus by the sum of local optimizations (a path integral, mathematically), a stone or a river always chooses the best path, a geodetics. From this very same standpoint, instead: *living objects go wrong most of the time*. A paramecium for instance does not follow exactly a gradient, in particular not in its preferred ecosystem, like a much polluted liquid solution; but it has a weak form of retention that allows a protensive attitude, as it can go the wrong way and thus learn. With *protensive* thus we mean a very basal attitude, proper of living beings, to act, interact and react, based on memory and along an expectation, as a primitive form of cognition. This allows to put in evidence a proper "biological inertia", which is part of the peculiar dynamics of organisms' actions and rarely a perfect geodetics (Longo and Montévil, 2011). Similarly, from an observer standpoint, evolutionary and embryogenetic paths are mostly wrong (most species are extinct and embryogenesis fails in a large percentage of the times).

This metaphor allows appreciating at the level of the outside observer the "question of error" that differentiates living organisms' from inert objects' paths. We should insist and make explicit the use made of *optimum* and *wrong* when we said that: "A physical object never goes wrong while a living object goes wrong most of the time". We took into account the perspective of physics and especially in the case in which *optimum* refers to a *geodetics*. Now, physics is not moral neither teleological, nor our approach would be teleological or moralistic, as we want to enlighten biological specificity in an enlarged, but physical and non-teleological perspective. In *physics* what goes right goes right and *it doesn't make sense* something that goes wrong, as we have discussed above. But in *biology* everything goes right or wrong *only and always from a particular standpoint* and *with crossing viewpoints* (see in particular next section, Berthoz and Petit, 2006). Only under the illusion of a disentangled observer, nothing goes right and nothing goes wrong, as it happens in physics where the universal laws reflect exactly this fact. On the contrary, in every position that is *situated*, *incorporated*, *contingent* and *autonomous*, which means necessarily in a determined space and time (even the standpoint of the fictional observer), there is a specific-individualistic viewpoint coming out. For instance, in an aggression of an organism by a virus the positions that emerge are radically opposed: what is right for one is wrong for the other.

Remembering Varela's closure thesis (1979), let's say that all possible variability of a living organism is organized, closed and immanent to the individual itself. "*Omnia mea mecum porto*", as the Stoic precept says; that we could translate here as "Everything I need is with me", which specifically claims the organizational-gestaltic autonomy referring to the organization and the self-standing independent unity that make the individual *being itself*. In other words the individual does not receive from "abroad" its autonomy: it *is* this autonomy. Let's specify that as every process also individualization is contingent and is led through the co-constituted interaction of the organism with the environment and through its history as we hinted above.

We can cross-refer to what said in previous sections. The contingency and the independence, which contributes to the specificity of the individual, moves along a generic, non-specific path. This generic path gains its determination contingently, through individual's life: it becomes a specific point of view with a specific memory only through actions, selection and evolution (both in ontogenesis and phylogenesis). In fact the intelligibility provided by Darwin's Evolution is not a predictive, but an historical one and it is largely based on failures. On the contrary the inert object moves along specific and, in principle, predictable (or at least determined) trajectories, optimal ones for every different object and by this it is an invariant of the dynamics (relatively to the reference system) as we will see in detail in the conclusion. We found pedagogically useful introducing this simple metaphorical opposition between the precise notion of *optimality* (geodetics) in physics and antithetically a concept such *going wrong* in biology, which makes sense, whenever it makes sense, only in reference to errors, to history and to a specific point of view.

6.

This crossing-over between physics and biology enlightens a conceptual line focusing on eccentricity and instability. The major components of this precious instability sketched till now are: constant variability, divergence from physical optimal paths and "errors" in general experience of exploring possibilities. All these are declinations of the permanent instability in a sort of Epicurus' παρένκλισις or *clinamen* in Lucretius' translation as we have seen in previous chapter (Lucretius, *De Rerum Natura*, II, 216-224 and 284-293). Therefore the eccentricity of the theoretical conceptualization of living beings in comparison to physical dynamics could be seen as a sort of *shift* from the centrality of mathematical invariance, so relevant in physics, towards structural stability and variability. Along these lines, it is possible to illustrate a comprehensive picture of some of the features that express and impress a *physical singularity* upon living organisms.

First of all, to understand the quavering "living state" of matter (Buiatti, 2000) and its processes one may introduce the concept of *extended critical situation* (Bailly and Longo, 2008). This concept comes along the lines of existing theoretical approaches in biology. In fact, we know from physics, in particular from the studies of the 1970s (Nicolis and Prigogine, 1977) that the analyses of self-organised systems far from equilibrium are relevant for a physical understanding of organisms. The physical study of critical states has enabled to highlight the presence of further examples of self-organization (Bak *et al.,* 1988). Thus providing the inspiration for a whole stream of studies that can be summarized in the idea of *self-organized critical state* emerging from chaos, or "order for free" (Kauffman, 1993) and the various theories on the *emergence* of complex structures from basic underpinnings elements (McLaughlin, 1992).

The concept of *extended criticality* proposes a conceptual and, then, a mathematical extension of these theories. The point of departure is that during phase transitions a number of characteristics occurs that show the shift from *local* to *global* – divergence of the correlation length for which infinitesimal variations create finite modifications, the appearance of order ... – in which the global structure is completely involved in the

behavior of the various elements (local structure). Again by a crossing-over, extended criticality opposes to the notion of criticality in physics, as critical transitions are mathematically defined for *point-wise* values of the control parameters. In the case of living beings, instead, the threshold of criticality is *extended* in time and is represented by a non-null volume in the space of all relevant parameters. Without entering in the discussion (Bailly and Longo, 2008; 2010), we can say that intuitively this is due to the capacity for adaptability and plasticity of living beings, which resists to variations (within broad limits) of the parameters (time, temperature, pressure...), while being in a permanent "state or phase transition". In other words the living state of matter may be resistant to modifications of the parameters, yet it is always in a *critical situation* in relation to its extended, but *limited* existence. Living objects are always on a threshold that changes dynamically: their entire structure of correlations (coherence structure) is transient between one phase and another, within the limits of a structural stability in relation to its ecosystem (Bailly and Longo, 2008; 2010).
A mathematical approach to extended critical transitions is being developed by our group[130]. Scale dependence and scale invariants are at the core of it. Subject to scale shifts, the focus of the analysis must be rearranged continually. We hinted here an expressive frame for this *eccentric translation* from physics towards biology, which tries to take into account also a translation of concepts. We believe that making reference to conceptual dualities is a way to give preliminary but "fundamental" level of intelligibility to the correlations of physics vs biology.

7.

Mathematical invariants are given by transformations that preserve them. Suitable categories of objects must be given jointly to their invariant

---

130 CIM…

properties, which are preserved through transformation (morphisms, functors). Such properties may be relative to measure, topological, algebraic… structures. In this frame:

- *Objects are domains of variation for* the intended mathematical variables. For example, suppose that a variable x is meant to vary on a topological space, D, say, where a continuous function h acts, with co-domain or range E. Thus, $h(x)$ is in E and h gives a "law", which is uniform in x (it *uniformly applies* to all x's in D). In physics the application is straightforward. Typically, Newton's law $f = gm$ applies *to all* physical bodies (*the intended domain*) and gives force or weight as a function of mass x, a property of a physical body: $f = h(x) = gx$, where g is the gravitational acceleration.
- in general, in a *physical law* any structuring of the intended domain, the distance or differences of mass, say, a metric, is transformed *uniformly* and effectively by law as a mathematical function.
- the situation may be more complex: "We have to solve equations", says Newton. In fact, equations provide the invariants that we may call "objective determinations": if they are invariant (stable), for example by symmetry translations in time, then energy conservation derives as objective determination from this very invariant (this is Noether's theorem, see (Bailly and Longo, 2010)).

Variables in the equations are thus *uniformly* handled as *ranging in the intended domain of variation*, hence they are *invariant*, uniformly transformed by a function, possibly a solution of the equation, *if any*. In classical dynamics, this solution usually yields the function h above as a specific trajectory (optimal).

We can correlate these two facts:

- *genericity*: generic objects are in the domain of variation *for* the intended mathematical variables (1);
- *uniformity and determination*: there is a *uniform* application of

mathematical function to all physical bodies (the intended domain) (2 and 3), every structuring of the intended domain is uniformly transformed by a mathematical function.

Now we can make a comparison with biology. Though it is *conceptually* heuristic and interesting to talk about a *domain of variation* referring to a living being, we need to underline some fundamental differences. First of all a living being *would be itself* that specific domain of potential variations, and not *in reference to* generic variables, as it happens for the objects of uniform variations. In fact, regarding the organism, as we have seen in relation to its autonomy and contingency, its peculiar domain of variation is autonomous in itself (closure) and does not refer in a pre-determinable way to anything else. Any variation is intrinsic (internal to the individual, yet in relation to the external environment) and correlated to unpredictable variability. There is no way to move aside or remove this entangled link between intrinsic variability, unpredictability of trajectories and unstable structural stability in biology. And the problem further increases when we move towards complex entities, such as humans, where our epistemological look becomes more and more demanding.

Nonetheless, there exist infinitely many and very relevant applications of this general physical-mathematical method in biology. In fact they concern many *properly* physical aspects of life and they are so well known and successful that everybody acknowledges their interest. We find more interesting to see, instead, *when*, *how* and possibly *why* this approach could go wrong, to use the expression mentioned above.

Suppose considering that the DNA is a mathematical invariant ranging on the domain of macromolecules. Then, one may refer to the genotype as a mathematical variable, to be transformed uniformly into a ... phenotype, say, which, if we translate into what said before, would be the set of properties of an organism given by a function h. This function h would provide a uniform law that gives the entire phenotype $h(x)$ for all macromolecules that have that DNA structure, x. This mathematically means that h is a function of x, but its definition must be *independent of* x as it applies uniformly and generally to *all* x's in the intended domain.

The law *h* would be Schrödinger's "architect" contained in the chromosomes themselves, as code-script (at once a program and an operating system in modern terminology).

8.

It can be easily grasped from what we said till now, how false it is defining embryogenesis as a *uniform function of DNA* (the invariant above) *independently of the interactions of DNA* with proteome, the cell and the global epigenetic context – including the whole organism which is being formed; and concerning heredity and development in the case of humans even the symbolic context is not negligible, as Jablonka and Lamb has recently recalled (Jablonka and Lamb, 2005). And it is not a matter of claiming that a living phenomenon "is more complicated" than the analysis of a falling body: it is conceptually different, as it requires theoretical extension of current theories of inert, as we said in the beginning and as Bailly and Longo have proposed in several papers. We need to invent or individuate a different family of concepts, which may capture the eccentric physical instability of organisms, as we have tried to underline above by means of several notions based on dualities and by extended criticality, typically. In fact, for no uniform effective transformation DNA can be analyzed as an invariant of the context and also: how many contexts and interactions should we consider? Nor the context is just "noise", to be regarded as *ceteris paribus* (Rosemberg, 2001). In fact, the result of all these destabilizing processes is nonetheless an *individual*, depending on historicity and on a contingent formation; so it would need *specific* and not *generic* notions, as both x and $h(x)$ are in a physical analysis. In biology, as we have hinted, it is the *path* (the embryogenesis or the evolutionary path) which is *generic*, though in different degrees. For example in evolution, possible paths are taken by speciation, selected by incompatibility, *never by optimality*.

This stands again in the opposition of optimum and wrong. The more complex the result of evolution is, in Gould's sense (and not in a teleological meaning, Gould, 1996) the larger are the differences in individuals' ontogenetic specification and their variability. This biological variability of the "end result" of ontogeny may be even contra-variant w.r. to the variability of the DNA: humans have much less variability in DNA than other primates, say. Yet, this is compensated, as adaptation process, by human very plastic brain and cultural variability.
Conceptually and theoretically wrong frames, such as the one gene one protein theory and the Central Dogma, dominated in large and consistent areas of biology for nearly half of last century. It determined a precise epistemological culture (Fox Keller, 2002). Starting from that theory, going back to the example above, one could possibly define a uniform and effective function h (even in the restricted sense of computable, or programmable) going from DNA, x, to proteins, actually to phenotype (or even to behavior, as claimed by many). Besides biological inadequacy of this mathematical approach that we tried to put in evidence, observe that the belief that there could be a linear process unidirectionally going through a context, like the cytoplasm of a eukaryotic cell, is even physically absurd. As a matter of fact, this theoretic frame was established by looking at specific cases in bacteria, where, exceptionally, they might apply, as presumably to other very few peculiar examples. But the quasi-turbulent frame of an eukaryote's cytoplasm, with quasi-chaotic enthalpic oscillations of macromolecules and largely statistical stereo-specific interactions, is a physically implausible frame for such a predictable (programmable) determination (programming is a form of "predictable determinism").

> Too often, the adaptationist programme gave us an evolutionary biology of parts and genes, but not of organisms. It assumed that all transitions could occur step by step and underrated the importance of integrated developmental blocks and pervasive constraints of history and architecture. A pluralistic view could put organisms, with all their recalcitrant yet intelligible complexity, back into evolutionary theory. Gould, Lewontin (1979), p. 598.

In conclusion, biological diversity is the result of a possible, contingent, evolutionary and ontogenetic path mostly failing and for this leading to an individuation. *Variability* must not be confused with the mathematical notion of *variable*, which beautifully applies to the *genericity* of physical objects and, by functions describing (classical) dynamics, provides the specific trajectories of each physical object. Though a word resemblance, the meaning and the domains of application are and should stay, as we hope to have thrown some light on, very different. Yet, correlated by conceptual dualities, which are a relevant form of correlation, in this case, between physics and biology. In a sort of variation on the theme of invariants.

III. Exchanging points of view: a phenomenological basis of the constitutive interaction in perception

1.

The main aim of *Phénoménologie et physiologie de l'action* by Alain Berthoz and Jean-Luc Petit (2006) is giving to a contribute to the philosophical foundation of a the physiology of action. This aim is quite peculiar, because scientists rarely involve themselves in writing on philosophical foundations. The book results from of the crossed dialogue between a neurophysiologist (Berthoz) and a philosopher (Petit). A merit of the volume is to the explicit the need of a change in the traditional approach concerning the interactions among disciplines and the ways scientists talk together. Berthoz and Petit observe this issue at different levels. Due to the great development of researches in different fields and in many directions, we are now spectators of a peculiar situation. On one hand, we witness a magnificent technical-experimental specialization; while on the other hand we begin to feel the need of more general questioning and theorizing. Moreover, apart from a few exceptions that the present work wants to focus, we assist to a radicalization of disciplines rather than to an attempt towards multi and inter-disciplinary account. On the contrary, Berthoz and Petit (2006) demonstrate this attempt in their program that they define a "document de travaille" (p.10).
Another main epistemological trait of their research is what they call the "posture théorique"[131]. With the term "posture" the authors try to express the main reference of their intentions. In fact, an empiric science such as neurophysiology normally does not feel the need or the pleasure of an epistemological formulation; on the contrary it usually takes advantage of an implicit epistemology for building and coordinating its hypotheses. Recalling the words by Claude Bernard "la physiologie est l'étude de la coordination des parties au tout", Berthoz and Petit underline that in physiology

[131] Ibid., p.37.

every experience grows on an implicit theory concerning the whole (organs, body, environment). According to them, trying to make explicit this implicit theory is the proper field of philosophical research. If we think to the definition of "posture" given by the Russian physiologist Bernstein as "preparation to act", then "posture" reveals its character "d'expression des émotions, elle est reflex de l'intention, elle est dictée par la culture, l'apprentissage social, etc."[132]. Therefore the notion of "posture" better than the term epistemology, gives evidence to the meaning of the interaction between physiology and philosophy.

To put in a nutshell, the theory of action proposed by Berthoz and Petit focus on actions and not on representations as the principal sources of cognition. Actions are grounded on lived experience or "expérience vécue" (*Erlebniss*), showing a constant dynamic between objects and subjects in their *Umwelt*[133]. Thus, without losing their intimate interaction and their co-structuring.

> La nouvelle physiologie de l'action doit donc être une physiologie de l'interaction qui dépasse le seul fait de construire des invariants (Ibid., p. 42, emphasis is ours).

In brief, keeping the "posture" as a starting point, the first issue becomes the critic of some theories founded on the representational model and their implicit reference to an epistemic subject[134]. We discussed in chapter one about the problem of a Universal Subject, here Berthoz and Petit underline this kind of idealization of the subject characterizing it as "the Sirius standpoint": a point of view that is far away as if it was outside the experience. The intrinsic corollary of this idea is the non-biologic concept of a reality that is absolute, not lived and not historical. These characteristics are identical to those described for the critic to the Universal Subject argument that we have underlined in chapter one.

This reference to an absolute world constitutes the ontological difference between two perspectives, that, as William James said, are the result of a limit-line traced in different points in the same

---

[132] Ibid. p. 37, N. A. Bernstein, The coordination and regulation of movement, New York, Pergamon Press, 1967.

[133] von Uexküll in his books describes the subjectivity of the worlds lived by animals according to their perspectives.

[134] See (Kim, 2006) especially chapter VIII.

world, thus representing also different gnoseological and epistemological standpoints. To better explain this issue, we may sketch a dual opposition having on one side a pole based on a monist-materialistic but dynamic and historical approach (Berthoz-Petit's position), while on the other side a pole sustaining a crypto-dualism, a Universal Subject, an absolute world and a representational point of view concerning the knowledge. On the basis of this main ontological opposition (monism-dualism), we can outline again three new antagonist conceptual-couples:

- monism/dualism (ontological)
- abstraction/intuition (epistemological)
- knowing/performing (gnoseological)

The dualism comes out from the fundamental scission made by the representational model between the absolute physical world and the represented world. Berthoz and Petit focus their criticisms on the analysis of the perception made by the representational theory.

> Les théoriciens qui interprètent la perception comme introjection de l'extérieur ou projection d'une représentation de l'intérieur, ils infiltrent ce que nous appelons un crypto dualisme et une répétition dans le caractère unitaire de la perception: dans l'espace il y a les choses physiques à l'extérieur, les représentations mentales à l'intérieur ; dans le temps vient en premier le stimulus rétinien, en second le percept – ou en premier l'image (mémorielle), en second la chose réellement perçue ; dans l'ordre de la causalité il y la cause (chose physique ou état du cerveau) et il y a l'effet (la représentation visuelle) (Ibid. p. 25).

The first thing that we loose using the representational standpoint is the gestaltic character of the perception, to which we already made reference. In the internal dimension of the subject we find other two interwoven levels where another duality occurs:

- from a temporal standpoint, the perception is described as the consequence of an answer to a stimulus, and correspondingly, from a causal standpoint, a representation follows or associates to a particular state of the mind.
- on the other hand, in the external dimension the physical world is conceived as a closed box full of objects with which we interact in a mediate way, always by means of a

representation.

We may recognize in this approach many of the traits we have already analyzed such as a deterministic vision of the interaction, or a stimulus-response model, or an analytical standpoint. This approach has the limit of proposing a static configuration of two opposed spheres, interiority/exteriority, subject/objective reality. Moreover, it seems inadequate when one puts in evidence the opposition between the typical opacity of structural and functional mechanisms of the brain and the presumed transparency of the external physical world.
The analysis of the second couple of antagonist concepts, abstraction/intuition, allows to evaluate the reflection of this same approach in the gnoseological point of view.
According to the representational theory, the logical-linguistic approach is considered as the unique form of objective knowledge apt to describe the subjective access to the interior world. In contrast, the objective knowledge of the exterior world pertains only to science's domain. We have seen another criticism of this traditional way of thinking in the claiming of the gestaltic character of the organizational process in perception made by *GT* (see chapter one). In that case, the idea was opposing to the analytical approach a synthetic approach that would grant a psychological science. Thus, the approach was experimental and grounded in observation but would not omit the qualitative aspects of experience, expressly leaning on the concept of intentionality. In Berthoz and Petit's proposal, the accent seems rather on the linguistic-representational approach to knowledge.

> Il faut lutter pour réhabiliter une philosophie de l'expérience, comme épreuve de l'être objectif. C'est un point commun aux auteurs de ce manifeste que la recherche d'une alternative à une pensée formaliste, qui fait passer le langage en tant que structuré en propositions logiques pour le seul moyen d'accès à cette connaissance objective (Ibid. p. 83).

It is interesting to remark that this discussion about the terms of knowledge in philosophy has a parallel also in psychology and in neurophysiology. Within this frame, a decisive argument emerges *i.e.*, the possibility of a rigorous definition of the representations and the interactions by means of the objects which are represented. Recent neurophysiological works propose in addition to a periphery-to-center model, or bottom-up model which describes the entry and processing of sensory data in the brain, a top-down model of signals processing and interactions. This model is determined by the anticipations that the brain develops before and during the perception and the action by means of descending influence of expectations on sensory acquisition[135]. This story is not new: David Hebb already criticized the behaviorism model of the brain as a black box, giving evidence to the importance of a neurophysiologic explanation of the behavior focusing on the interaction between efferent and afferent ways in a cell assembly (Hebb, 1949)[136].

> I. L'idea generale è una vecchia idea e cioé che due cellule o sistemi di cellule che si rendono ripetutamente attive in contemporaneità, tendano a divenire associate, in modo tale che l'attività di una faciliterà quella dell'altra. (L'organizzazione del comportamento, 1949, pp. 136-137)[137].

> II. Ogni stimolazione particolare, frequentemente ripetuta condurrà al lento sviluppo di una organizzazione cellulare, una struttura diffusa comprendente cellule della corteccia e del diencefalo [...] capace di agire brevemente come un sistema chiuso, erogante facilitazioni ad altri sistemi simili e solitamente dotata di una specifica facilitazione motoria. [...] Ciascuna azione di organizzazione può essere suscitata da una interazione-organizzazione precedente, da un evento sensoriale oppure, di norma, da tutti e due. (Ibidem).

> III. La teoria è evidentemente una forma di "connessionismo", una delle varietà della teoria del quadro di controllo, sebbene essa non tratti le connessioni dirette fra vie afferenti ed efferenti: non dunque una psicologia "stimolo-risposta", se risposta significa una risposta muscolare. (L'organizzazione del comportamento, 1949, pp. 62-65)

From Hebb's words we should note three important points:

---

135 Berthoz, 1997.
136 For a detailed analysis see Dazzi, Mecacci (1982).
137 Hebb D.O. (1949), The Organization of Behavior: a neuropsychological theory,Wiley-Interscience, New York.

- the recognition of the possibility of coupling of two cells as a result of their frequent contemporary activation. This effect, which canalizes specific correlations, works legitimately as a functional and later as a structural constraint (see previous section II.). This point, known as Hebb's Law, is meant with the slogan: "Neurons that fire together wire together".
- the link between an organization event and both sensory data and another interaction-organization event. We recognize here the process of emergence, in which a new emergent organization comes out from the interaction between new perceptions and previous organization-interactions.
- the criticism of the railroad train metaphor for the functioning of the brain, as expressed by the stimulus-response model. In contrast to this model, the connectionist approach and the metaphor of the control panel[138] are proposed, and the non-linearity of the process is specified; underlying the emergent processes of the interconnected networks of more simple units.

In the same years, Bernstein, the father of the "physiology of the activity" focused on motor control and motor learning, and showed the contextual-environmental interactions at work in every observation of the animal behavior. And in particular he proposed to observe more directly the interaction of the animal in its proper environment. In this context, Bernstein put into light also the role of the feedback-mechanisms in the action's control and regulation. The feedback became the key for explaining the continuous brain readapting to the continuous interaction with the environment, in a sort of direct-line adaptation. Bernstein had been an inspiring mentor for Berthoz and Petit's theorization. As we will notice, many of the theoretical assumption of Berthoz and Petit and their idea of "conjoint activity" recall some of Bernstein's ways of thinking; especially at the epistemological level and in the opposition with the representational approach.

In the following lines we quote some passages of Bernstein's tuned to our present discussion on the concept of interaction and its historical development by means of antinomic standpoints on the

[138] For an overview on the metaphor of the brain see Debru, 2010, cit.

subject. In this way, we may recognize here many of the points that we have already enlightened.

> I. Questo approccio analitico allo studio delle condizioni di immobilità derivava dal tentativo di studiare ogni organo e ogni processo elementare in isolamento, tentando di escludere effetti marginali o interazioni mutue.

The first element that we note here is the criticism of the isolation procedure. As already mentioned, rather than considering the processes in their development *i.e.*, real processes, interacting, connecting, changing, interfering, developing, it was established to study phenomena as much isolated as possible by means of the elementariness principle (elementary process, or organ, neuron, etc).

> II. In termini generali questo approccio corrispondeva al predominio dell'atomismo meccanicistico nelle scienze naturali di quel tempo.

> III. L'assolutismo di questo punto di vista ha portato alla convinzione che l'intero è sempre la soma delle sue parti e non più che questo, che l'organismo è un insieme di cellule, che tutto il comportamento è una catena di riflessi e che una conoscenza sufficiente dei singoli mattoni basterebbe a comprendere l'edificio costruito su di essi.

In this two quotations we see the critical description of the simple juxtaposition of parts rather than their organization in a global structure that *GT* (*Gestalttheorie*) put into light.

> IV. Il secondo aspetto si riferiva al concetto che l'organismo vive in uno stato di equilibrio con l'universo che lo circonda e che questo rigido equilibrio viene mantenuto per mezzo di reazioni appropriate, senza relazione l'una con l'altra, che si hanno per ogni stimolo successivo che, proveniendo dall'ambiente circostante, urta contro l'organismo.

> V. L'intera esistenza e il comportamento dell'organismo venivano visualizzati come una catena continua di reazioni in un modello stimolo-risposta (input-output). L'insegna dei fisiologi materialistici classici era l'arco riflesso e il loro fine centrale era

> l'analisi delle regole delle reazioni considerate come relazioni input-output determinate in modo rigido.
>
> VI. Vecchia fisiologia dell'immobilità e dell'equilibrio. Per la verità i movimenti sono praticamente le sole espressioni dell'attività vitale dell'organismo. I movimenti sono i mezzi con i quali esso non solo non interagisce passivamente con l'ambiente, ma attivamente agisce su questo in qualunque modo ciò sia necessario. (Indirizzi e problemi nello studio della fisiologia dell'attività 1961, pp. 14-15).

I think that the focus made by Bernstein on motion is very interesting for its peculiar point of view emerging. Motion is view as a fundamental sign of life, in contrast to the conception of an element breaking the equilibrium, as proposed by ancient physiology, that Bernstein defines "of immobility and equilibrium". The idea that the organism is in a state of equilibrium goes together with the metaphor of the railroad train in which all movements are determined by the parallel railroads lines that never cross themselves. This equilibrium is a sort of heaven where nothing happen. On the contrary, Bernstein put into light the co-constituted active interaction between the organism and the environment based on activity and dynamics.

We may recall in these criticisms also the idea of the second conception of interaction based on integration that we have opposed to the linear one in the configuration of the two-opposed approaches *i.e.,* analytical vs synthetic.

Reading the words of Bernstein, Hebb, Berthoz and Petit, we may find the proposal of making explicit the myths that are at the basis of the behaviorism stimulus-response model and the representational theories. In the quotation V. by Bernstein we may find the interesting suggestion to look at the epistemological underpinning of this conception ("L'insegna dei fisiologi materialistici classici era l'arco riflesso e il loro fine centrale era l'analisi delle regole delle reazioni considerate come relazioni input-output determinate in modo rigido"). We want to stress the notion of reflex-arch, because in our opinion this is one of the main epistemological underpinnings responsible for the development of the deterministic-analytical way of interpreting of the concept of interaction. The notion of reflex arch considers things as

interrelated in chains of actions and reactions, and in this world, to recall the expression we used in chapter one, there is no space for inter-actions. We may even move forward asking if in such a world of chains of actions and reaction there is in fact possibility/dynamics/space/freedom for a proper action to happen, but this would bring us much further beyond the aim of this work.
Anyhow, along these lines lays the epistemological opposition between knowing and performing. The representational model poses these two processes on two distinct plains, while the action theory presents the fact of being able to perform an act or the "savoir faire", as a knowledge tout-court (Ibid. p. 59). We should specify that this kind of knowledge does not lose the character of objectivity, rather this same objectivity is reinforced by the direct-live study of the experience. The main argument of this approach is that the brain compares sensory data by means of projections and does not treat information (Berthoz, Petit, 2006, p. 56). In fact the center of the problem of a theory of action is how the brain may develop the mechanisms which are correlated to the knowledge. For instance, Vygotsky proposed an evolutionary model focused on the idea of the "tool", as "historical-cultural" extensions of the brain functioning (see chapter one). With this approach Vygotsky describes the contingent development of the brain, together with the evolution of the environment, the ideas and the culture by means of their reciprocal dynamics-interactions in the course of individual's experience and history.
Berthoz and Petit focus on the concept of anticipation:

> Plutôt que subordonner la sensation à la perception et la perception à l'action, c'est a l'acte qu'il faut accorder la priorité; acte qu'on retrouve identiquement dans le sentir, le percevoir et l'agir (Ibid. p. 60).

The act is a process of continuous actualization of the perception, which is not accomplished in itself, but it is always re-actualized. Many different systems are interconnected in order to provide the anticipation, we cannot give an outlook of these systems here (among others: sensory receptors, inhibitory mechanism of sensory perception, corollary discharge and efference copy, posture, simulation of trajectory; Mazoyer, Berthoz et al., 2000; Burgess, 2006). Anyhow the interesting aspect of this proposal is trying to put the problem of the nature of action into a dynamic which responds to an evolutionary need, but not only to that. One should understand dynamically the interaction mutually occurring between the organism and its *Umwelt*. The experience in fact is built and comprehended by virtue of anticipatory constructions, due to protentional constitution.

This position is grounded on Husserl's epistemology and particularly on the conceptions of *Leib* and *Kinesthesis*. We cannot discuss broadly here this story, which brings also to the critical discussion of the approach named "naturalization of phenomenology" (Petitot (ed.), 1999; Frezza, 2007). We limit to remark some main theoretical points which are relevant for the present discussion on interaction.

Naturalizing phenomenology approach originates as an answer to some questions in cognitive science field; the center of these questions is the relation between cognitive science and phenomenological data. One of the main ideas of the approach, proposed also in the book Naturalizing Phenomenology (1999), is to provide a better understanding between cognitive processes and their phenomenological appearances. This implies a discussion of cognitive science theories and in particular an attempt to fill the so-called explanatory gap. In brief, cognitive science is not a consistent gnoseological theory because on one hand it proposes some solutions to the mind-body problem, on the other hand it excludes some mental phenomena. In particular, it is not able to account for a mental phenomenon from a subjective point of view. In other words, it is still open the question of the difference between having consciousness and what happen to a conscious mind. In a sentence: if the mind-body problem has been at the center of philosophical debate, we assist now to a focus on mind-mind problem[139].

---

[139] Jackendoff, *Consciousness and the computational mind*, MIT Press, Cambridge (Mass.) 1987; trad. it., *Coscienza e mente computazionale*, il Mulino, Bologna, 1990. For the mind-body problem one should distinguishes between different perspectives, for instance a central system focus or in strictly phenomenological terms the distinction between *Leib* e *Körper* (Husserl, 1912). See also an interesting critic of cognitive approaches from the point of view of morphological tactile-somatosensory human constitution (Mazzeo M., *Tatto e linguaggio*, 2003).

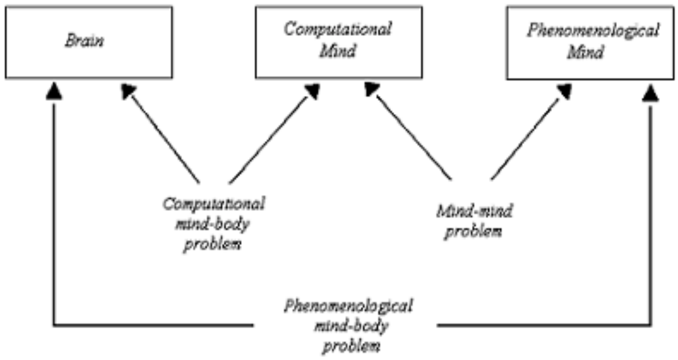

Figure 1. The explanatory gap according to Jackendoff; the figure sketches the unsolved relation between cognitive mind and phenomenological mind.

We should remark that the major interest of the Naturalizing phenomenology approach is taking into account this aspect (mind-mind problem) avoiding the risk of leaving it to a non-naturalistic approach, seldom leading to a mysterious dualism spirit-body. Naturalizing phenomenological data in this sense means integrate them in an explanation frame within which every described property is in continuity with the properties accepted by natural sciences. A key element of this approach is not prevent oneself from asking what does mean the fact that something *appears for* somebody that is taking into account the phenomenological aspect of experience. This aspect, as we have remarked is a very similar objective to *GT*'s proposition of a "qualitative science of the experience". Anyhow, in extreme synthesis, is still open the question of how instituting this return to Husserl's phenomenology nowadays, from a naturalized point of view, when understanding that Husserl's proper intent is intrinsically non-naturalistic (1913). The transcendental trait of the Ego is absolutely in itself before every mundane body. In this sense, Husserl suggests that philosophical investigation quests for "qualcosa di diverso per principio da ciò che cerca la scienza positiva e deve proporsi qualcosa di diverso da un dominio teoretico, raggiunto attraverso l'esperienza, sul mondo già dato"[140]. According to Husserl, this position does not mean to propose an ontological dualism or a duplication of the world, rather it is an

[140] Husserl (1913), «Postilla alle Idee», op. cit., p. 424.

invitation to reflect in different modalities about the unique material existence which is offered in our experience. In a nutshell one wants to remark with this approach that it is not possible to investigate a pre-constituted world, independent from the active living subject. Thus, rather than focusing on separated activities, one looks at their synchronic functioning.

Berthoz and Petit make a semantic torsion of those phenomenological concepts. This torsion allows, in their opinion, passing from a purely theoretic plan to a naturalized one. One therefore should put into light the performing character of the subject that determines *a priori* the objects of his possible knowledge. In other words, the center of Berthoz and Petit's idea is that the brain is a comparative projector rather than a tool which traits information (Ivi, p. 56). An example of this complex process is the reference frame activated during visual perception. This mechanism is based on hypotheses of rigidity, symmetry and stability that the brain would anticipate in the visual process (Ibid., p. 106; Wexler et al., 2001). Or in the terms of *GT*, we will say that the reference frame is activated by means of autochthonous factors that give to the observed objects their saliency traits and their gestaltic character.

Underlying this anticipatory trait, emphasis is given to the temporality and materiality traits of the experience, in contrast to an abstract and rigid dogmatism.

> L' a priori en question ne se présente pas sous la forme d'une règle logique, d'un principe épistémologique ou d'une connaissance innée, qui seraient inscrits dans l'esprit indépendamment de l'action. C'est un a priori de l'expérience. (Ibid., p. 108)

Berthoz and Petit synthesize this kind of architectural functioning of experiencing the experience in three stages.

- at a first level the brain makes an analysis of the world that is called "spatial filtering" (Ibid. p. 111).
- a more dynamic dimension, ecologic and reflexive, adds to this plan, as a result of the active interaction with the world, oriented by intentionality. In short, this interaction is a sort of orientation that produces a constant modification of the analysis of the experience.

- at a third level, every act itself is continuously linked with a memory device, which grants that every modification and also the new experiences could be easily activated.

In this way time structuring plays a role which is itself constitutive of time: “Le temps c’est ce qu’on est obligé de simuler en interne avant le mouvement” (Ibid., p. 110). Let us remark this conception of time that is one of the more peculiar traits of individual living experience[141]. The time subjectively constituted is the global factor of the continuous production of projections, which the brain displays during the development of the perceptual experience within the whole life of an individual (Ibid., p. 113). This is the reason why the act, which is always *ex post*, is the articulation of a nonstop production of time in its all declinations: present, future and past. In his famous analysis of time (Husserl, 1928) Husserl called this structure protentio-retentional (*Protention-Retention*)[142].

> Per comprendere, ora, l’inserzione di questa unità di vissuti costituita che è il ricordo, nel flusso unitario dei vissuti, bisogna tener conto di quanto segue: ogni ricordo contiene intenzioni d’aspettazione il cui riempimento conduce al presente. Ogni processo originariamente costituente è animato da protenzioni che costituiscono e captano a vuoto ciò che ha da venire, come tale, e lo portano a compimento (Husserl 1928, § 24, p. 84, ed. or., p. 44-410).

The way protention and retention are connected is determined in the experience, but at the same time this is an *a priori* condition of the experience itself.

> Ogni nuovo retroagisce sul vecchio, ed è così che si riempie e si determina la sua intenzione anticipatrice: il che conferisce alla riproduzione una colorazione precisa. La retroazione che qui emerge è dunque necessaria a priori. Il nuovo rimanda a qualcosa di nuovo che, comparendo, si determina e modifica le possibilità di riproduzione del vecchio e così via. (Ibid., §25, p. 85, ed. or., p.

141 For a mathematical description of the double orientation of time in individuals see (Longo, Montevil, 2011).

142 E. Husserl, Vorlesungen zur Phänomenologie des inneren Zeitbewußtseins, Max Niemeyer Verlag Tubingen, 1928.

46-412).

The main difference with other neurophysiological internal modeling proposals is the accent on the lived experience (Berthoz, Petit, 2006, p. 118), which is an inheritance of phenomenological analysis[143]. In particular three main concepts from Husserl's analysis – *Reduktion*, *Intentionlität*, and *Abschattung* – gives a rigorous basis of the analysis of the perceptive act, of the constitution of the *Leib* (proper body) and of the intersubjectivity (Husserl, 1928; Husserl 1913; Husserl 1950) are also the main references for the theory of action. If we make reference to Berthoz-Petit's theory, the essential trait that connects these three concepts (*Reduktion*, *Intentionlität*, and *Abschattung*) is the dynamics of the organized perspective that emerges in every experience (in its various knowing-performing modalities). In fact, in summary (Frezza 2007) the *Reduktion* allows to start an analysis of the experience with a point of view that is refined from every interpretation already acquired or imposed: it indicates a sort of *a priori* light skepticism concerning every environmental "data" and what is "traditionally considered as data", as we have already anticipated (Husserl, 1912); in other words, it suggests to make a change of the "mental posture", to come back to the Berthoz-Petit's notion. This approach is, in our opinion, an important epistemological premise, which can be easily acquired from phenomenology and be adopted nowadays in a naturalized epistemology. It may help granting a good point of departure, avoiding dogmatisms and providing a tool which continuously re-orients the research. On the other hand, the *Intentionlität* guides and fills the sight, which had already been oriented by the *Reduktion*, and by means of its analysis we become aware of the determination of sense emerging from the unavoidable relation between the conscience and the objects of the experience. In brief: every object of my perception makes sense for me, the object becomes consciousness of something or it is "full of an intelligible content". In this process there is an emerging character to which we have already made reference (the possibility in itself as an opening, but

[143] AA.VV., *Naturalizing phenomenology. Issues in contemporary phenomenology and cognitive sciences*, (eds.) Petitot J., Varela F.J., Pachoud B., Roy J.-M., Stanford University Press, Stanford, California 1999.

contemporary as a constraint of the experience). Recalling *GT* discussion, “we see what we can see”, we are always focused on minima and maxima areas of saliency and all the rest stands in blind spots. At last, the *Abschattung* is a further restriction of the perceptual horizon, it is exactly the aprioristic discrimination and parceling out of the perceptual horizon by means of *Gestalten*, that we have mentioned previously. The interaction and the encounter that one has with the objects and the bodies around him (also with human beings), may happen only and always in a partial way. By means of anticipations, the perception gives us a vision in perspective, which is continuously modifiable and which aims a sort of promise that “something more will arrive” (Berthoz, Petit, 2006, p. 135). In Husserl’s description there are series of continuous perspectives of a perception (*Mannigfaltigkeit*)[144] constituted by motivated images of the things and the motivating *kinesthesia* series determining the link between the various stimuli arriving from different sensory fields. In the example of the visual field, every series of images is correlated with an ocular movement (called saccade) that is perceived by the subject as an internal sense of movement (corollary discharge) (Berthoz, Petit, 2006, p. 151). Nowadays it is possible to make a parallel between the motivating series of Husserl’s analysis and the corollary discharge in neurophysiology, *i. e.*, the signal sent to perceptual centers about the movement accomplished by the effector (the eye).[145] In this way the activity of the post-central regions is inhibited, thus making explicit to cerebral centers that motor activity is made by the subject itself, not by the objects in the world.

> S’il y a pour nous des choses pleinement spatiales, c’est que nous sommes capables de mettre en œuvre toute une série de mouvements dont nous sommes avertis par nos kinesthèses dans le moment même où nous les accomplissons (Ivi, p. 164).

We should remark the priority given to the role of the movement for the development of the perceptual experience which is critical for the traditional sensorimotor paradigm. In contrast to this paradigm the term motor-sensory is proposed (Ivi, p. 164). The other

[144] Husserl, 1913, §72-3.

[145] The corollary discharge is sent from the centers involved in the movement (pre-motor and motor regions) to other structures involved in the perception.

characteristic, which results from the integration between *Reduktion*, *Intentionlität* and *Abschattung*, is an idealistic aspect. This aspect should be intended as an opening on the always intrinsic "possible" dimension of the experience especially put in evidence by Husserl's eidetic approach. In every perception, in every lived experience a part of idealization is already at work, or, in other terms, it is present an infiltration of the virtual over the real (Ivi, p. 144). This approach contrasts with the "empiricist naturalistic dogmatism" or also of what Husserl called the dominion of the science of factual data. We should remark also that this approach does not want to reintroduce a set of "Ideen" existing independently from the brain functioning and from the world experience. Rather it wants to make explicit the "double movement" (anticipatory and constitutive characters) of the lived contents of consciousness that we have described as *constitutive*.

> Un mouvement à la fois, de constitution d'un monde qui apparaît à partir d'interprétations qui contiennent une part d'abstraction et, d'un autre côté, une pré spécification de ce qu'on veut percevoir en fonction de son but[146].

Thus according to this description, in a perception, a transversal potential horizon is opened at the same time of the actual happening of the perception providing the multidimensionality of the experience and its indefinite extensibility (Ivi, p. 155)[147]. This opened horizon is configured through an imaginative variation that constantly keeps alive in a projective way the continuity of the series of the object (Ivi, p. 166-8)[148]. To delineate in a wider scheme this argument we can sketch the integration and the coordination of these levels:

- the correlation of different kinesthetic systems and their correspondent perceptive perceptual spaces
- the orientation of kinesthetic spaces with the movement axes allowed by the body, as those of the object and together with terrestrial locomotion

146 *Phénoménologie et physiologie de l'action*, op. cit., p. 145.

147 That is also a reason for the reference to a proto-object rather than to an object which in fact is yet in course of formation, in a pre-phenomenal experience.

148 There is a vast literature on Husserl's imagination conception, among others see (Ghiron, 2001; Bernet, 1996).

- the temporal and dynamic constitution of all kinesthetic systems with the object fields made by everyone of those systems
- the series of possibilities always intrinsic in the actual series

One could see that in this description the focus is in the dynamics of the interaction between the subject who is acting and the material experience. As Husserl remarks, the possibility of the idealization of an *objective abstract space* is determined only as an over-limit setting, at the end of the material process already experienced. Thus, following the progression of the different kinesthetic systems levels in an increasing order of complexity. Before every concept of space one should ontologically posit the possibility of the direct personal (in the first person) experience of the world and at the same time in the inter-personal standpoint (Ivi, p. 165). In this interaction between object and subject, the subject's primary contribute is the constitution of the meaning[149].

> La contribution du sujet, c'est *le sens*. Il y a pour lui un sens, et ce sens, quoi qu'il en soit par ailleurs de l'objet qui en est doté, n'est que par rapport à lui[150].

We could resume the interaction between the body and its *kinestheses* saying that the body is the very peculiar locus of tautological relations that at the same time confer to it a double and a paradoxical character. From one side I am my body, it is an objective reality in the world and at the same time it is the locus of the double connection (Ivi, p. 218). But on the other side this condition reveals a paradoxical feature because the body follows in its constitution that of its organs (Ivi, p. 201). From a neurophysiological standpoint one can describe distinctively the different internal models that concur in the constitution of the bodily scheme in a formal-functional analysis. Unlike external objects for which is possible a configuration of different

---

149 In Husserl analysis the meaning is the noematic correlate of the noetic act, the thing to which the subject is intentionally directed. In a very synthetic formula I may say that reducing everything that is stratified in every act of meaning (for instance from a linguistic or cultural standpoint) one gets the access to the noema: the meaning in its original form or in its proto-semantic form. See in particular Hua XIII, Zur Phänomenologie der Intersubjektivität, Texte aus dem Nachlaß. Erste Teil: 1905-1920, hrsg. von I. Kern, 1973;

150 *Ibid*.

perspectives which together determine the individuation and the identity of the perceived object, for the personal body every isolate analysis is impossible. From one side I make an identification with my personal body which is unique and always mine; in Husserl's words: "everything can escape me but my body" (Ding und Raum, p. 280). From the other side we can always make only a limited analysis of the body. The phenomenological approach allows formulating a hypothesis keeping together these ambiguous and fragmentary aspects[151]. In this way Berthoz and Petit propose a change in the traditional approach of neurosciences :

> C'est-à-dire ne plus considérer le corps propre seulement comme résultat de ce qu'on appelle aujourd'hui une *intégration multisensorielle*, mais passer pour mieux appréhender son sens à la catégorie de l'action[152].

In fact this focus on action highlights that the unity of the personal body is never given at once, rather it is developed by means of the anticipation mechanism and the articulation of the motivating series (Ivi, p. 204). In this way the sense of touch becomes the original source to reach a consciousness of the personal body, innovating the traditional view by which it is the sense of vision which is considered more fundamental[153]. Recent evidences about the incorporation in the bodily scheme of the object which is manually used allow to establish a fundamental relationship: the mechanism at work during the manipulation of objects contributes to the constitution of my body and, at the same time, it allows keeping the integrality of the object identity (the used thing) (Ivi, p. 210-217; see Iriki *et al.*, 1996).

> Cet outil est enveloppé dans une transaction à l'interface des deux systèmes, celui des perspectives objectivantes de la perception et celui de l'appartenance au corps propre[154].

We can distinguish three main entangled levels contributing to the

---

151 Ibid., p. 192-204. See J.-L. Petit éd., «Repenser le corps, l'action et la cognition avec les neurosciences», op. cit. For the notion of bodily scheme as internal model of the body see V., Levick Y.S., «Perceptual and automatic aspects of the postural body scheme», in J. Paillard ed., *Brain and Space*, Oxford University Press, 1991, p. 147-162.

152 *Phénoménologie et physiologie de l'action*, op. cit., p. 206.

153 See also (Mazzeo, 2003).

154 *Ibid.*, p. 212-213.

constitution of the personal body conscience consciousness

12. the kinesthetic motivating series (KO) of external objects
13. the kinesthetic constituting objectivity series referred to the personal body (KOPB) that configure it as an object of the world
14. the kinesthetic motor series (KM) that constantly inform it about the desire of moving and about its yet oriented intentionality.

The most important feature of the kinesthetic motor series by means of the progressive integration and co-evolution of the somatic-motor and somatic-sensory topographic maps is that they form a back-forward efference system, continuously contributing to personal body plasticity and dynamics (Ivi, p. 220; Llinas, 2001). The maps of the bodily scheme are plastic and not fixed as it was thought (Mezernich *et al.*, 1983).

> La somatotopie des aires secondaires sensorielles doit être reconnue comme plastique. Plasticité modulée par l'expérience du sujet tout à long de sa vie et largement contrôlée par son activité motrice dans l'usage du corps propre et d'autre choses[155].

Another fundamental trait of the constitution of the experience and of personal body should be noted. Changing the horizon of reference, from the personal we can move towards the plural standpoint. And show the basal structuring of living beings, particularly humans, in intersubjectivity. Husserl develops the idea of the constitution of the proper body by means of its interactions with the environment together with objects and other people. He supposed that the understanding and the recognition of the other was possible in virtue of the interplay offered by our spontaneous co-constitution in intersubjectivity. Accordingly, Berthoz and Petit stress that it is not necessary an inferential mechanism of the condition of the other in order to recognize the other (p. 237). Starting from the concept of action, which is itself constituted in interaction, they focus on the common *Umwelt*.

> En vérité, nous voyons quelqu'un structurer activement son monde parce que nous-même, déjà, sommes capables de structurer notre

[155] *Ibid.*, p. 224.

> monde par des actes. Il y a une identification profonde des subjectivités, liée à leur rôle identiquement constituant[156].

They underline also the complex dimension of intersubjectivity. This is made by the coordination and interaction and entanglement of many different levels; thus, for instance they criticize one of the first proposals defining the Mirror neurons as a "neural foundation of intersubjectivity" (Gallese, 2005). It would be much more appropriate to delineate many different mechanisms appeared in the middle of evolutionary selection, rather than one only *system for* intersubjectivity[157].

In this way we touch the core of Berthoz-Petit proposal: intersubjectivity can be related with the possibility of changing the point of view of our perception and put one self in the other's standpoint (p. 243; Berthoz, Jorland (eds.) 2004). Thus transposing the Ego from its ontological constitution, they propose an Ego which is already plural. This constitutive transposition of the Ego is in fact a constitutive act which concerns the multiplicity, the plural co-constitutive existence of the Egos. On these lines they propose to call the underpinning of the concept of intersubjectivity a "conjoined action" (p. 248-9). We think that the interaction in its stratified meaning (gestaltic-organic-interference-active) could be well explained with this concept of conjoined action. Again suggesting that on the contrary the deterministic and analytical formulation of the concept of interaction in this specific case should be definitely dismissed. The development of anticipatory and projective aspects, by virtue of the structuring of the *kinestheses* and the continuous modulation of the bodily scheme, has essentially an individuating function (p. 251). This process of recognition and of individualization exactly as the *Abschattung* phenomenon in perception is always dynamic *in perspective* and never totalizing.

We insist on the connection of *Reduktion*, *Intentionlität* and *Abschattung* as we want to differentiate it from skeptical or relativist approaches in gnoseology (Conant, 2004). Even if phenomenology presents these premises of reduction and precaution concerning reality and the possibilities to know it at the same time

---

156 *Ibid.*, p. 243.

157 See also the critics to the "broken mirror theory" for explaining autism dysfunction in children, for an outlook (Frezza, 2009).

this approach introduces an expressive difference with relativism. What Husserl wants to enlighten is not that we are not sure that there is an external world or that it is not conceivable (Nagel, 1974), rather that there are transcendental conditions that founding our interaction with the world[158]. In our opinion this point is a "cleaning up" standpoint in epistemology that produces a non-dogmatic approach. Here, we have seen it directly in Berthoz-Petit's work, but we think that it could be always be remembered as a possible point of departure, especially when one tries to follow interdisciplinary routes (Bernard-Weil 2002). In fact the risk of going into the railroad metaphor for conceiving processes, brain functioning, stimulus-response and representational paradigms is just around the corner, as we have underlined many times in this work. We should interpret the design of *Phénoménologie et physiologie de l'action* as theoretical "posture", as the proposal of a direction of research focusing on the interaction and the exchange between different disciplines ideas. Action is understood as a working model hypothesis useful both for philosophy and physiology researches, as well as a point of view allowing intrinsically this same interaction. I want to underline that in this standpoint there are both disciplinary specialization and philosophical insight, leading to a methodological and theoretical interaction, or, using an expression that we have already put in evidence, there is attention to procedural processes and dynamics rather than to static essentialist-dogmatism. The interaction becomes a virtual and dynamic space that is created in-between the standpoints of the disciplines. From one side this space means a specific and rigorous employ of disciplines' concepts, but on the other side this space delineates a dynamic tension in the continuous and always renewable development of new concepts and ideas. Starting from common problems of philosophical and neurophysiological investigations, the model of the action theory reformulates the constitutive relationship of subject and object in terms of conjoined action. The strong point of this approach is the possibility of a plural constitution that at the same time as projective and anticipatory traits. Thanks to this plasticity proper of

[158] For the debate on the presumed internalism and solipsism of Husserl see his *Cartesianische Meditationen und Pariser Vorträge*, hrsg. Von B. Strasser, 1950; tr. it. F. Costa, Bompiani, Milano, 1989.

living being constitution (especially developed in humans), we are able to *co-mprehend* the other in the dynamic which is formed by various possibility of the experience within the same world that is constituted in a conjoined way.

> La rencontre de deux disciplines ne se fait pas lorsque l'une se met à réfléchir sur l'autre, mais lorsque l'une s'aperçoit qu'elle doit résoudre pour son compte et avec ses moyens propres un problème semblable à celui qui se pose aussi dans une autre[159].

[159] Deleuze G., «Le cerveau c'est l'écran», *Cahiers du cinéma*, n°380, février 1986, p. 25-32 *in Deux régimes des fous*, Les éditions de Minuit, Paris, 2003, p. 265.

IV. *The society of cells*: an analysis of the hierarchical levels' interactions in explaining living beings' organization

Il peut donc être profitable de chercher les éléments d'une conception de la science et même d'une méthode de culture dans l'histoire des sciences entendue comme une psychologie de la conquête progressive des notions dans leur contenu actuel, comme une mise en forme de généalogies logiques et, pour employer une expression de M. Bachelard, comme un recensement des «**obstacles épistémologiques**» surmontés !
G. Canguilhelm, 1952, p.

Quæso ne hæc legentes, quoniam in his spernunt multa, etiam relata fastidio damnent, cum in contemplatione naturæ nil possit videri supervacaneum[160].

1.

In reason of the very many interesting things that Carlos Sonnenschein's and Ana Soto analyze in their book, *The society of cells. Cancer and control of cell proliferation* which I could not take into account here in this limited space, I have decided nonetheless to put in evidence in particular two main conceptions of theirs: the proliferation default state of cells and the tissue interaction approach to cancer explanation.
I start with a quote from the very beginning of the script,

[160] *Prego coloro che leggono, nonostante in cio' molte cose vadano disprezzate, di non avere fastidio a causa delle cose riportate, visto che nella contemplazione della natura nulla puo' essere considerato superfluo.*

considering that it is also one of the central issues if not the main target of Sonnenschein's and Soto's research.

> While you are browsing through this book, billions of cells in your body are actively proliferating. At the same time, probably an equal amount of cells, if not more, are not. Why? Sonnenschein, Soto (1999), p. ix.

The questions arising from this very "simple" fact concerning cell proliferation are at the center of Sonnenschein's and Soto's theoretic speculation (from here on: S&S)161. They can all be summed up in a light formula: *why* do cells proliferate?
The philosophical idea that underpins S&S's researches is that once one has come over the quest for an *explanation* one cannot be underwhelmed by questions about the causes - *the why and the how* - of phenomena, and consequently one cannot be satisfied with descriptions animated by a dogmatic research protocol as we may call it.
As a start we will try to follow S&S topics, experiments and discussions to proceed, then, a bit more into their philosophical questioning, or into their "intellectual journey" as they refer to it. I may start with introducing and clarifying some terms, as I have done many times in this work. The difference between "cell growth" and "cell proliferation" in metazoa is one of the main point in S&S discussion. "Cell growth" is *currently* used to refer to *cell development* as well as to *cell division*. But in the life of a cell the term "proliferation" is also used for talking about *cell division*. One should straightaway remark that this last concept more properly than "growth" recalls the meaning of "reproduction" that is concretely what we are talking about when we want to mean cell division. One of the main points of this argument would be the need of explaining why "cell growth" is then "currently" used to refer to cell development. We should underline that S&S in particular refer to higher eukaryotes in which the term "reproduction" has different meanings when related to *a cell* of the organism or to the *entire organism* as well for the term "growth" or "development". In vitro, instead, the situation is different, a eukaryotic cell can grow as a

[161] In shortening Sonnenschein-Soto's names to their cut or ground zero formula I wanted to avoid every SS symbol, while the formula SaS stands for society codes (such as Scandinavian Airlines, or the French code for the "Société par actions simplifiée"...) thus I have chosen S&S.

bacterial culture and thus the term “grow” means specifically *cell division*.

S&S put into light that as a result of the techniques that were used in the manipulations made in the beginning of past century it was not easy at all to determine the “rates” of cell proliferation. Before the introduction of autoriadiography techniques (Bélanger, Leblond, 1946) and labeled thymidine in the ‘50s, it was quite difficult to attest the difference between just divided cells and their quiescent homologue[162]. It is Charles Philippe Leblond, a Canadian biologist, with his colleagues who took advantage of autoradiography procedure for introducing radioactive precursors of DNA; this allowed to give evidence of the proliferation and fate of several basic tissue types cells. In their analysis for instance they proved for the first time that most cells and tissues in the adult body undergo continued renewal, giving also a precise mathematical account of the turnover and mitotic rates of numerous cell types. All these kind of experiments and techniques led to consider a peculiar “time dimension” of cells and tissues, putting up the underpinning for discovering proper cell cycle (C.P. Leblond and Y. Clermont. “Definition of the stages of the cycle of the seminiferous epithelium of the rat”. *Ann. NY Acad. Sci*. 1952, 55, 548 573).

S&S’s point is that since that time a general standard hypothesis concerning the analyses on proliferation rates has been diffused:

> Manipulations that resulted in the increase of proliferative rates in the tissues of adult animals were equated with a positive signal (i.e. a stimulus or a trigger) ... Regardless the nature of the agents used, and their physiological relevance, researchers must have considered these agents as stimulatory; implicitly, they were validating the notion that the *default state* of cells in multicellular organisms was quiescence because cells proliferated in response to what they perceived as a direct stimulus. (S&S,

[162] In 1946, Charles Philippe Leblond, a Canadian biologist, discovered that a liquid photographic emulsion became activated when made reacting with a histological section containing a radio-element. Moreover if standard photographic fixation was applied to the emulsion-covered section, black silver grains appeared in the emulsion in contact with sites containing radio-element. Bélanger, L.F. and C.P. Leblond, “A method for locating radioactive elements in tissues by covering histological sections with a photographic emulsion”, *Endocrinology,* 1946, 39, p. 386-400. Hereafter this approach has been used to develop High Resolution Autoradiography procedure at close contact, which allows to detect the radio-elements in the section at high resolution. Gross, J., R. Bogoroch, N.J. Nadler and C.P. Leblond. “The theory and methods of the radioautographic localization of radio elements in tissues”. *Amer. J. Roentgenoi*. 1951, 65, 420-468.

1999, p. 4-5, our italic).

The first elements we should start to throw light on are the two subsequent equalities below:

1. *increasing* of proliferative rates = *positive* response to a signal which induces that
2. *positive* response to a signal = *default* state of cells is *quiescence*

We see that the idea is to attribute a positive, stimulatory capacity to some agents that made cell proliferate. As we have already learned from what previously said, we should be alert when something that may take into account a polarity is referred only to one of its sides, here (and very often) the positive one. Concerning the positive response to the signal which activates a higher level of proliferation our lesson would then be: let us look at the other side of the coin to see what it is hidden behind. We should consider then the negative response to the question of the control of cell proliferation, which is exactly what S&S have done. Their explanation of the positive interpretation of cell proliferation is scientists' anthropocentric attitude ("anthropocentric factor"). To put it even plainer I should add that it is a sort of "maternal instinct" in experimentation for which cells in culture conditions are considered proliferating *because* the scientist (the mother) provides the stimulus, or the nutrients, as growth factors.

> Originally growth factors were meant to be the substance and conditions (pH, oxygen pressure, etc.) necessary for the optimal growth of organisms, rather than signals that controlled their proliferation. (Ibid. p. 7).

In this sentence it is implicit the assumption that the default state of quiescence is anyway determined by an active control. The polarity of the proliferating or quiescent state is determined by an equilibrium of functions leading to one or to the other possibility were probably what we divide in two functions could be described as one part of the same cycle. In the picture stressed by growth factors approach we may ascertain a sort of essentialist attitude which, instead of looking at what it is currently happening to things, considers things as done, in a fixed perspective or in a dogmatic research protocol to which strictly attain to. As we have put into light many times here we can stress the opposed standpoint which comes from a functional or procedural attitude and which does not consider things as done or facts, but much more as (re)agents, in function of their interactions. To gain yet another point of view for discussing this epistemological polarity I think that is worthwhile to recall briefly a point made by Canguilhem in reproaching Compte's empiricism. In that occasion Canguilhem pointing out a genealogy of theories underlines that Compte made an equality between "chronological anteriority" and "logical inferiority":

> Identification qui conduit Comte à consacrer, sous l'influence d'un empirisme pourtant tempéré de déduction mathématique, la valeur théorique, désormais définitive à ses yeux, de cette monstruosité logique qu'est le « fait général ». Canguilhem (1965), p. 62-63.

It is not possible entering in the commentary of Compte-Canguilhem discussion, but on the contrary we have already remarked the monstrosity of the "general fact" that here Canguilhem puts in evidence, for instance following Husserl's researches; and here again it seems very useful for research purpose to distinguish between observation and *general facts*. Any time one focuses on general facts forget the dynamics of nature in its organizational dimension which should take into account, constraints, evolutionary crossings, emergence, all completely opposed phenomena of general facts. And because scientific observation is an interactive domain one has always to handle the polarized dimension of interaction, thus, we should resume:

- no general facts and
- always two sides of the coin.

On these lines Paul Weiss in the text "What is growth?" (1960)[163], rather than the general established positive model for cell growth, considered the importance of negative control, underlining also the complexity of the term growth; this instead in his opinion was used indiscriminately by the scientific community. He remarked that "growth is a term as vague, ambiguous and fuzzy as everyday language has ever produced" and he checked out all the possible

[163] W.W. Nowinski(ed.) , *Fundamental aspects of normal and malignant growth*, Elsevier, Amsterdam, pp. 1-16.

definitions of it to which biologists were referring to, such as “reproduction, increase in dimension, linear increase, gain in weight, gain in organic mass, cell multiplication, mitosis, cell migration, protein synthesis”. I would love to say that this argument may be perfectly appropriate to refer to my discussion about the term “interaction” which as we have put in evidence in the introduction has been proliferating in the last years and has being used in so many meanings such as cooperation, interference, communication via signal, exchanging information, etc. and in many different subjects, such as physics, psychology, genetics, evolution, media and communication. Thus already we may say that a need for clarification of concepts and of the employment of the concepts by the scientific community seems to be appropriate.
Anyhow, going back to S&S’s analysis, from the half of last century different groups started in an independent way to develop negative control hypothesis (Weiss, Kavanau, 1957; von Bertalanffy, 1960; Soto, Sonnenschein, 1984 and 1987). All those perspectives added some interesting elements to the research. In fact, instead of a unique standpoint that relates cell growth with cell proliferation the two processes started to be questioned from a hierarchical and integrative point of view. So staying at S&S definition we can say that:

> Growth is an increase in size of an organ or organism. When dealing with the tissue hierarchical perspective we can avoid the use of the notion of “growth” by using the more appropriate terms *hyperplasia* for increase in *cell number* and *hypertrophy* for an increase in *cell size*. (ivi, p. 6).

Here we see a first important distinction that one may straightforward applies in practice: the term growth might be replaced by *hyperplasia* for increase in *cell number* and *hypertrophy* for an increase in *cell size*. As we said the emergence of the radioactive tracers in the years ‘50 permitted many different improvement in the research.

> The cell cycle was then defined by two measurable events, DNA synthesis (S phase) and mitosis (M phase), and two ‘silent’ intervals, called G1 phase (the period between completion of mitosis and the start of DNA synthesis), and G2 phase (the period between the end of DNA synthesis and the beginning of

mitosis). (S&S, 1999, p. 8).

Figure 1

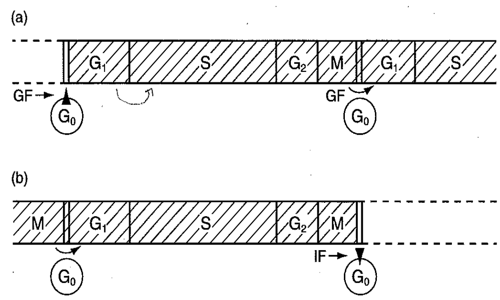

Figure 1.1. Schematic representation of the control of cell proliferation. (a) In the positive control hypothesis, the growth factor (GF) induces a quiescent (G_0) cell to enter the cycle. (b) In the negative control hypothesis, the inhibitory factor (IF) induces the cell to enter the G_0 state. The shaded area represents the cell undergoing the cycle. The arrowheads indicate the transition between the default and the regulated state.

It becomes evident, as S&S remark, that at this point there are two conceptual decisions to take. In fact no evidence appears without the precious contribution of both intuitive and rational insight. The first decision to make is choosing between the fact that cells are:

- *always performing the cell cycle*
- or rather that they *move in and out of it* (stopping in the arrest point called G0 in figure 1).

If one chooses the second possibility, thus that cells move in and out of cell cycle, then arises the question whether the default state of the cell is *quiescence* or *proliferation*. If the default state is quiescence, thus no endogenous activity of the cells, then the control of proliferation is necessarily made by positive signals such as growth factors. That is why this option is called the *positive control hypothesis* (see figure 1). If we look at the other side of the coin, thus if the default state of the cell is *proliferation*, thus endogenous activity of the cells, then the control is necessarily mediated by *negative signals*, via inhibitory factors. This second option is called the *negative control hypothesis* (see figure 1). On the contrary, if one chooses the first possibility above, thus that cells are permanently in the cycle, control of cell proliferation and control of "cell cycle traverse" are one and the same (when the cells are committed to cycle they proceed traversing it inexorably),

suggesting then necessarily that the one and only default state is anyhow *proliferation* (Ibid., p. 9). In fact there would not be another way of inducing the activation of proliferation as the cells are always performing cell cycle.
I said that we had to take two conceptual decisions, the first being just described. Then our discussion leads now to another distinction and clarification. Traditionally the convened and established default state of the unicellular domain is proliferation (S&S, 1999, p. 9). On the contrary in multicellular organisms the default state is much more difficult to assess,

> because the internal milieu contains not only nutrients, but also signals to control the proliferative activity of many cell types. This means that to study control of cell proliferation experimentally the researcher unavoidably has to decide a priori whether the default state is quiescence or proliferation. Clearly these options are mutually exclusive. (Ibidem).

The importance of this last choice has a counterpart in a more ancient debate about *organicism* versus *reductionism*, and as S&S remark should be considered together with the evolutionary path of these very basic processes; for instance how multicellular organisms evolved from a single cell or a zygote. S&S's idea is that one should consider the *hierarchical organization of nature* as the main trait or as the general standpoint to attain to in describing living beings.

> Occasionally, by focusing our attention at lower hierarchical levels (biochemical and molecular) we lose perspective of the very reason of our research on multicellular beings, that reason being to understand organisms, including ourselves. (Ibidem).

We had occasion to remark in chapter one the importance of the notion of "constitutive experience" à la Husserl and also of the organizational endogenous character of processes, what here is named the "hierarchical organization of nature". I want to specify, as the term may inopportunely suggest, that hierarchical does not want to mean a qualitative denotation, rather it refers to the idea of different levels of organization of nature and of our experience of it. Traditionally this standpoint is the one adopted by scientists who study evolution and who has to take into account the different levels

of life's organization subject to changing and evolution. For instance classical neo-Darwinists see the evolution as a change in the alleles' frequencies and thus consider as evolutionary unity just the genes, the people who study development on the contrary give emphasis to the organism, natural science's scientists are particularly concerned with species as well as ecologists study the evolution of the ecosystems (Buiatti, 2008).
As we may comprehend the "hierarchical" way of thinking puts into light an analogous opposition of the "particular observer" versus the "universal subject" point of view to which we referred in chapter one. And as we stressed with James' metaphor of the line of division of the theoretical universe, also the meaning of interaction comes along with the particular theoretical standpoint that one chooses to assume. We noticed that the two emerging ideas of the concept of interaction, "algebraic" opposed to "gestaltic" one could be correlated to two other opposed standpoints in theoretical research and in the language used for research: *reductionism* (elementariness) and *organicism* (vitalism) or *analytical* and *synthetic* approaches. Under these premises we will not be surprise in finding now *one of these two* specific interpretations of the particular interaction that we are talking about concerning cell proliferation.

> The success of biochemistry was based on the premise that the interaction of discrete components in a test tube would give clear, unambiguous answers because of the limited number of variables affecting the outcome of those interactions. (Ivi, p. 10).

Here we find something that clearly puts in evidence the employ of a reductionist approach: if we reduce the number of the variables we may get the impression of touching the core of the interaction and think to be describing it in mathematical or discrete terms (compare this with the description of Bailly-Longo's commentary in previous section). This interpretation is, as every interpretation, made under precise premises, but moreover does not take into account the characteristic indetermination or the interference phenomenon involved in an interaction: thus its polarity and its multi-factorial aspects and the phenomenon of emergence. Objects at one level of organization interacts with other objects giving rise to more complex levels of organizations, such as the difference between a cell to cell interaction or tissues interactions, as we have seen also concerning Connectionism neurons networks.

> Limiting the number of components may be a convenient strategy to identify causal agents; however this should not quell concerns that there are other unsuspected, or ignored, variables that can significantly affect the results obtained with a limited strategy. This is in fact what may be happening in real life; hence, the lack of reproducibility of results that once worked in the test tube but fail to occur in more complex, organized environments (a cell, a tissue, an organ, a system, an organism). (Ivi, p. 10).

It is quite evident that the theoretical premise which the scientist choose in his/her research gives also an indication about the particular standpoint he/she is concretely employing in the analysis. Limiting is yet simplifying, thus a very important and clever strategy for science developments, but the possible risk in this account is as we mentioned a reification in this simplification-approach with a theory ad hoc which bypasses the consideration of the hierarchical levels of observation. We will see also other examples of this reification-approach which underlines how it is very well established in science and in scientific language. And again also the notion of interaction is not excluded by this reification approach, as we discussed in the introduction. The great increasing in the employment of the term interaction in recent thirty years studies by itself suggest a peculiar epistemological circumstance. The question that rises is: to which need this situation answers, or in the name of what? I want to stress that putting into light the polarity of the notion of interaction does not mean that one is technically or *de iure* obliged to choose a priori a particular standpoint (analytical or synthetic) or hypotheses (positive or negative). On the contrary, the idea is that the utility of the polarity perspective should be taken into account globally, as a general premise apt to develop a heuristic point of view! Nonetheless as we said, because in research and theoretical practice this choice is ineluctable, de facto we have suggested where our preference would go.

Going back to the problem of hierarchical levels of analysis, as S&S emphasize biological phenomena frequently do not receive a clearer picture when observed at a lower level of analysis with respect to their original level of investigation. Nonetheless, at the same time discovering underpinnings may reveal a "continuum of features" that helps in enriching higher-level description. For instance, it is not very useful to analyze the structure of the muscle fiber component myosin when trying to illuminate how the heart works as a pump; but on the contrary the mechanism of striated muscle contraction has been understood exactly when its underpinning structure was already described.

> This implies that to comprehend a given biological phenomenon each hierarchical level should be studied without expecting that lower levels of inquiry will contribute to the understanding of that particular phenomenon. In addition to 'bottom-up' emergence, there is a reverse emergence, whereby the organism as a whole affects the properties of its parts [see Mayr, 1982]. (Ivi, p. 10).

We should decide then whether, with the Jammer's words mentioned above, with this reductionist approach the "barriers" we need for describing the organism become too narrow. We may relate this with the problem of the unities of analysis that *GT* had put in evidence. One needs to *focus* on a *proper unity of analysis* conscious of the possibility of a great operation of reductionism included in its plan. Thus the very problem is how to know which is the proper unity of analysis?
As we may have already understood this choice implies a theoretical step: assuming explicitly and consciously the theoretical premises with which one is moving into the analysis.

> Pragmatically, this is the only sound path to follow. The body data available to the researcher always shows inconsistency, contradictions and exceptions. Choosing to trust one set of data over another, or to adopt one premise over others, is subject to a reasoned, though sometimes intuitive, decision. (Ivi, p. 11)

I want to remark here not only the importance of this conscious assumption made by the researcher, but also this idea of an intuitive component acting or interacting inside conscious and responsible decision. Again an interaction, again a polarity: intuition versus rational decision. "After all, uncertainty is the daily concern of scientists" (Ivi, p. 11).
Our problem here is questioning about the default state of

eukariotes multicellular organisms. Thus, for instance, one may take into account the evolutionary point of view which at least gives us a well structured universal perspective to look at phenomena. In the analysis on microorganisms one of the main processes described in prokariotes' life is in fact *dividing* ("The dream of a bacterium is to become two", Jacob, 1974), thus proliferating. This activity particularly depends on nutritional need, because starvation usually leads to cell death. Some bacteria for instance need specific nutritional requirements to grow which were formerly interpreted by researches as *growth factors*. Other microorganisms developed some strategies to survive starvation such as stationary phase (Steinhaus, Birkeland, 1939) that correspond to a sort of cannibalism which allows to get nutrition from the digestion of the dead bacteria. Others have instantiated spores traffic, which by means of the diffusion of the capsules grant a form of "latent life" that becomes active only when in contact with a more generous situation. Anyhow, even this very state, which eventually differs from quiescence not being a metabolic activity, puts in evidence that proliferation is a constitutive property of prokaryotes (S&S, 1993).
The case of unicellular eukariotes comes along these same lines: proliferating. Some, such as parasites, are dependent on hosts' nutritional equipments, others have developed the ability to reproduce sexually, forming gametes when their nutrient supply runs low. Sexual strategy gives the advantage of an "amount of time" disposable when nutrition resources get low; in fact sexual reproduction requires more time that the asexual way, granting the possibility of a fewer, but sure, amount of organisms, which anyhow, in spite of sure extinction, is practically an advantage.

> These examples illustrate that the *ability to proliferate is constitutive in these organisms*, and that control mechanisms evolved to curtail reproduction during starvation. Hence quiescence has never been an option for unicellular organisms aiming to reach the limit of their proliferative capabilities. (Ivi, p. 16).

Even if one should hypothesize that in the case of multicellular organisms some emergent properties have come out as a result of the interactions engendered in the more complex field, one is not reasonably supposed to hypothesize that multicellular organisms *should have fallen out of the evolutionary path of their ancestors*:

thus changing from proliferation default state to quiescence one.

> Biological problems should be interpreted in the context of evolution. (Ivi, p. 20)

Another important remark concerns control of cell number. Cells number is maintained through a balance between cell proliferation and cell death, depending from the tissue, and the organs interested. For instance while in the liver the proliferation is very low as well as cell death, in the endometrium there is a constant cycle of cell proliferation and cell death. In these kinds of tissues were the rates of cell proliferation and death are high cells number is mostly regulated via an alteration of cell death (Williams, Smith, 1990, p. 28). The two ways cells have to make death happening are necrosis and apoptosis. The metaphor generally used to explain these phenomena are death by murder for necrosis and suicide for apoptosis. In necrosis, in fact, tissues are sent to death by means of a starvation from oxygen and other nutrients, while apoptosis does not require an external event to take place, thus can be considered auto-inferred164. Anyhow one should notice that the control of cell death is a "conceptually independent phenomenon" from that of cell proliferation: it plays a role in morphogenesis and on the control of organ cell numbers (Gilbert, 1997, p. 40). Cell proliferation and cell death are not necessarily and conceptually related.

Let us go back then to explain the phenomenon of cell proliferation in multicellular organisms. The interactions among cells, their topology and evolution (such as for instance has been put in evidence by Evo-devo theories), modulate also their proliferative activity. As a sketch one may resume some principal characteristic of these interactions:

- *cell-to-cell recognition* by means of secretion of specific proteins in the plasma recognized by receptors (juxtacrine or paracrine interactions)
- *cell junctional complexes* that binds cells together are responsible for the tridimensional organization of tissues and for proliferation patterns in tissues (Bryant, Schmidt, 1990; Bryant, 1997, p. 28)

---

[164] Apoptosis in adult tissues was first explained in the 1970s (Wyllie, Kerr, Currie, 1980, p. 28), later on many studies were made at a biochemical level which lead to the description of concurrent effect such as DNA degradation, or induction of specific genes (Leist, Nicotera, 1997, p. 28).

- *organismal secretions* that act upon target cells located in other organs (endocrine mediators, such as blood-borne hormones)

As we have already mentioned there is a consistent difference from the in vitro experiments about cell proliferation and in vivo results. In the 1920s one of the main concerns was defining a medium for the propagation of cells in culture. The fact that most cells died when exposed to chemically defined media, determined that "the serum-supplemented medium remains the accepted universal nutrient solution for cells *in culture*" (Ivi, p. 22; Willmer, 1965, p. 29). This phenomenon anyhow let unexplained the question: "what was present in the culture dish and absent in the animal or plant that justified the relentless proliferation of some cell in glass and later on in plastic flaks?" (ivi, p. 22). As we said we have to wait the early 1950s to get more proper technical devises to grant a quantization of cell proliferation and the analysis of its control165. But with DNA structure discovery a changing in the attention of researchers' interest become to spread around, till the 1970s when a "sizable number of scientists working in prokariotes switched their attention to somatic cell genetics" (ivi, p. 23).
S&S have individuated a rupture point in this epistemic path in the article by Eagle and Piez (1960, p. 29) which was "accepted by the scientific community as evidence that plasma proteins played no other role than that of carriers of signals (proliferation regulators/growth factors) that would have induced the entry of cells into the cycle" (Ivi, p. 23). In fact if

> before then, growth factor just meant any nutrient that when added to culture medium contributed significantly to make possible the propagation of a given cell, or to increase its proliferation rate. After Eagle and Piez, growth factor meant a signal to move metazoan cells from quiescence to proliferation. In short this notion strengthened the perception invoked by predecessors and contemporary observers that quiescence was indeed the default state in metazoa (Ivi, p. 23).

Between the end of the 1950s and the early 1960s there is in fact a

[165] See Moscona use of trypsin to detach cells from each other and from the glass surface in which they grew (Moscona, 1952, p. 29). Only later on, starting from the '60s and the '70s, the introduction of the electronic particle counting machine by Coulter started to be diffused.

sort of *convergence of researches towards somatic cell genetics and cell culture* (Earle, Waymouth, Evans, Eagle) the interest of which was even more incremented by Levi-Montalcini's discovery (1986, p. 29) of nerve growth factor and Cohen's analysis about growth factor in submaxillary gland of mice (1986). The drastic comment made by S&S and sustained also by other researches is that:

> the almost 40-year research program based on the premise that quiescence was the default state in metazoa has neither developed effective serumless formulations for the long-term propagation of cell lines, nor has it demonstrated that the role of serum is to provide ultimate signals to trigger cell proliferation (Ivi, p. 25).

Evidences on plants cells on the contrary show that they are auxotrophs that proliferate in defined medium and again following the evolutionary line also plants as prokariotes and unicellular eukariotes have proliferation as a default state of cells (Steward, Kent Mapes, 1966; Willmer, 1965).

2.

> The study of the control of cell proliferation, like another area of experimental science, depends on at least two types of prerequisites: first, the development of hypothesis to be tested, and second, the development of appropriate tools and methods with which to test them. (Ivi, p. 31).

We may now briefly resume some main experimental results and hypotheses concerning cell proliferation and then put them into the context of the more general theoretical frame that we have been describing till now trying to "test" them.

- by evidence of some animal models studies in multicellular organisms cell proliferation is regulated by means of different interactions between cell types and signals (during histogenesis, organogenesis and maintenance of cell numbers in adulthood).

- the high complexity prevents cell proliferation control to be studied in vivo, thus normally it is observed by means of a single cell type and single extracellular variable.
- cell proliferation is a discrete function. The only parameter that allows comparisons of proliferative activity is the doubling time of a population.
- if one accepts as default state *quiescence* the regulatory agent (*growth factor*) must significantly decrease the doubling time.
- if one accepts as default state *proliferation*, the controlling agent (*inhibitor*) must significantly increase the doubling time.

The two main hypotheses for cell proliferation control that emerges from this picture are a *positive* hypothesis (gain of function) and a *negative* one (loss of function). S&S make the example of liver cells, as in rodents, for instance, “the removal of two-third of the liver is followed by the rapid restoration of the organ mass within the next 48-72 hours, with a complete remodeling in about a week” (p. 41). If one chooses the *positive* option it requires *firstly* the induction of a proliferative signal by the cells and *secondly* a negative signal for stopping proliferation activity. And by means of the positive option one leaves unsolved the problem of indicating to cells the loss of parenchyma and the need of the production of liver-specific growth factors. While, if one chooses the *negative* option it results that:

- the concentration of a putative *inhibitor* of liver cell proliferation is maintained *constant* at effective plasma levels in intact animals
- immediately after the partial hepatectomy, the *inhibitor* level would *decrease*, triggering the *proliferation* of the remaining *cells*
- finally, as the *cell numbers increase* to reach those present in intact controls, the plasma levels of liver-specific *inhibitor* would *increase*, thus
- *shutting off the proliferation of liver cells* (see figure 2 above)

Figure 2

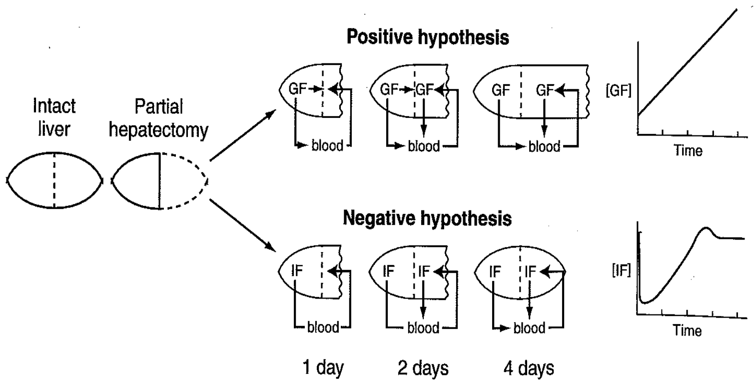

Figure 4.1. Schematic representation of liver regeneration after partial hepatectomy according to competing hypotheses for the control of cell proliferation. The positive control hypothesis does not account for a predictable end of the proliferative period once the liver mass is restored to its pre-hepatectomy cell number status. The plasma concentration of an inhibitory factor (negative control hypothesis) is proportional to the liver cell number and parsimoniously accounts for the initiation and cessation of cell proliferation [2].

The problem that arises is that this controversy nowadays is still an open question (Ivi, p. 43, Bard, 1978). But as we said in the beginning of this paragraph we need also to put the experimental hypotheses into the frame of a more general explanation.

The *positive* hypothesis has as main premises:

- that the default state of metazoan cells is *quiescence*, as an axiomatic quality
- the quiescence state of metazoan cells *in vivo is equivalent* to the quiescence state of metazoan cells *in vitro* subjected to serum starvation
- *culture conditions provide* via the defined medium *all the nutrients* needed for survival
- serum provides both metabolic regulators (*hormones*) and signals to induce cell proliferation (*growth factors*) (Alberts et al., 1994, p. 56)

The *negative* hypothesis, on the contrary, is based on the opposed and mutually exclusive premises:

- *proliferation* is the default state of all living cells
- cells will exercise their constitutive, built-in capacity to proliferate *when adequate nutritional requirements are met*
- cells will proliferate when extracellular or intracellular

inhibitors are absent, or their down-stream *effectors are inactive*

The more suitable experimental model that has been elected for studying cell proliferation control is sex-hormone in reasons of its well established characteristic of "signals that affect the proliferation and trophism of their target organs and cells" (S&S, 1999, p.60). In fact after the administration of estrogens in the female and androgens in the male there is a proliferative response in the epitelial lining of their respective target organs. It is important to notice that only the cells that have specific receptors are able to recognize sex steroids as signals. It has been recognized that target cells lines for their capacity of mimicking their normal counterparts can be studied in culture, even if avoiding the various direct interactions operating in the whole organism (S&S, 1999, p. 61).
Different researches (e.g. Martin, 1980; Stormshak, 1976; Kumar et. al, 1987) have put in evidence that:

- estrogen receptors operate as transcription factors, which are necessary in the process of estrogen-induced gene expression
- in the absence of estrogens, the receptors are inactive
- once the receptors bind to estrogen, they become activated; that is they interact with specific DNA sequences, and with other transcription factors
- this in turn allows transcription of the specific genes into mRNAs which are next translated into specific proteins

During the 1970s research programs on estrogen action held that estrogens *directly stimulate* the proliferation of their target cells, via the estrogen receptor, by inducing the entry of the cells into the cell cycle (*direct-positive hypothesis*).

> In other words estrogens were postulated to be the ultimate positive signal that induced cell proliferation. Soon thereafter, we faced a paradox: namely, while these cells developed into estrogen-dependent tumors when inoculated into animals, in culture they proliferated at the same rate regardless of the addition of estrogens (S&S, 199, p. 63; see S&S, 1980).

One may find it very interesting also as a commentary about research discoveries that S&S decided to renovate their research protocol and shift into another hypothesis starting from the paradox

of a different response in in-vivo and in-vitro cultures. In the mid-1970s they became convinced that estradiol was the *proximate* and not the ultimate cause of the proliferative process. In fact estradiol administration to animals did not increase cell proliferation in some of the normal tissues and neoplastic cells that carried estrogen receptors. Thus, while estrogen receptors might be *necessary* they *might not be sufficient as a cause* of the proliferative response to estradiol to occur (S&S, 1999, p. 63; Uchima, 1991). The other remark is that there are not data confirming a direct proliferative effect of estradiol target cells in culture. This leads to the conclusion that estradiol effected the proliferation of its target cells *indirectly* (S&S, 1987). As result a first synthesis of these data was adopted in an *indirect-positive hypothesis* in which there is an intermediary step requiring the intervention of growth factors secreted by estrogens target organs under estradiol stimulation (Sirbasku, 1978; S&S, 1978).
In this hypothesis there were anyhow some difficulties: experiments data were not gathered by counting the cells. We said previously that the only *rigorous measurement* for cell proliferation is the *doubling time of cell populations* during exponential phase of proliferation, and finally there was also lack of foundation about the role of pituary gland as source of estrogen-induced growth factors. Again a paradox made by many complex and not-convergent data in which the problem is the interpretation. As we hinted before, staying in this difficulty in correlating experience with theoretical assumptions, one should probably look at which premises one felt *rationally*, *responsibly* and also *intuitively* more “attracted” to, in order to chose between the two hypotheses. In fact as S&S explain data based on “conflicting paradigms can seldom be reconciled. This is because when researchers, explicitly or implicitly, adopt opposite premises they design experiments addressing different question”(Ivi, p. 70).

> It became plain to us that the above-mentioned paradox *in animalia/in culture* could be resolved by just switching the premises. Namely, instead of adopting the premise that cells were quiescent waiting for the positive stimulus(i) to signal that they should enter the cycle, now one could postulate that cells were always ready to proliferate, and that they would do so unless a specific inhibitor(s) prevented them from expressing this constitutive, built-in ability. (Ivi, p. 65).

This switching of premises, from quiescence to proliferation as cells default state, leads to the *indirect-negative hypothesis*. As already mentioned, a good heuristic approach seemed also to be evolutionary comparison. Another reason for opting for the negative control hypothesis was based on the analysis of the conservation of the default state through evolution (Ivi, p. 55). Other data put in evidence also that mouse vaginal epithelium explants proliferated regardless of the presence of estradiol in the serumless medium (Martin, 1959; Flaxion, 1974), reinforcing also S&S' hypothesis that the postulated inhibitor was blood-borne . All these evidences made very clear that the growth factor hypothesis for proliferation could be dismissed.
We have already had a reason to talk about the importance of the *artificial character* of observation concerning every reductionist approach necessary in experimental conditions, and we remarked also the opposed experimental tendency which focuses more into the environmental interactions rather than in isolating elementary phenomena.

> All experimental models are by their very nature 'artificial'. Researchers chose as models, the species or strains, or developmental stages, in which the phenomenon they are interested in is most homogeneous, so that it may be studied without interference from overlapping or unrelated events [...]. Organ and primary cultures, along with 'established' cell lines offer a reduction in complexity, together with an increase in 'artificiality'. Researchers compare the relevance of the *in-culture* results to those of their *in-animal* counterparts; these latter are the ones they are trying to understand. (Ivi, p. 72).

In the case of the three hypothesis we are treating, *positive*, *indirect-positive* and *indirect-negative hypothesis*, for instance human breast tumor cells do not proliferate in ovariectomized hosts unless estrogens are administrated to the nude mice into which they were inoculated (Soule, Mc Grath, 1980). On the contrary in-culture experiments were interpreted as the proliferation of these cells in the absence of serum, was indicative of the ability of cells to produce their own growth factors. In fact the rationale was that cells derived from tumors, thus abnormal, shifted from their quiescence default state to an abnormal one, leading to *abnormal*

proliferation. As we said above, in the lack of new data, the only way a researcher has to feel its commitment to a paradigm rather than its opposed one is supported by its personal decision and intuition and depends on the "premises researchers believe are the most likely to 'represent' reality" (Ivi, p. 73).
In this specific situation there is again an arbitrary choice to be made, since the default state of metazoa cells is not already determined by today experimental evidence. One should remark, wheresoever, the correlation between chosen premises and experimental construction.

> This means that often experiments designed for one set of premises cannot be interpreted from the perspective of the opposite ones. For example, only if one suspects that serum may contain an inhibitor of cell proliferation would one test the effect of decreasing serum concentration to find out when the inhibition was no longer effective. (Ivi, p. 73).

Here we find again the theme of artificial condition vs natural ones, simplification vs reduction, analytical vs syntactical approach that we have already compared with Oppenheimer's stratification analysis of reality and scientific knowledge. Everything in these questions seems to gain a polarity. As a first conclusion suggestion I may try to introduce here a methodological commentary from the point of view I'm trying to clarify with the present work. I may say that according to which interpretation of the concept of interaction one is more attached to, and interprets that better "represents" reality, then one chooses differently the paradigm to which he/she decides to be committed and vice versa. Recent evidences clearly demonstrate that inhibitory and stimulatory effects both participate to the control of cell proliferation underlying also in this case that this kind of mechanism is a physiological function largely diffused in all biological phenomena. The life of cells is controlled for the division as well as for cell death. Both processes are regulated by inhibitory and/or stimulatory effects. In other words each of the two functions can be altered by gain or loss of one function. We see that we assist nowadays to an increasing in the complexity of the representation and description of biological phenomena. Nonetheless, the polarity perspective on interactions seems to be a peculiar feature for a large amount of biological organization. The great change arrived with the “reading” of the human genome, and since the first attempts to discover the function of the different sequences discovered it was clear that many concepts about structure and function of our genome should have been changed and particularly the role played by genes.

> Si avvio’ cosi’, paradossalmente con il trionfo del metodo riduzionista, un processo che ha portato allla sconfitta delle teorie meccaniche, e alla possibile soluzione delle antinomie di cui si e’ parlato, verso una nuova visione della vita. Buiatti, (2008), p. 70.

This very revolution had been already put in evidence in the physical study of complex systems in the years ‘80. In particular, as we have seen in chapter one, the antinomy between deterministic and random systems was clarified, making explicit the fact that in nature do not exist neither completely determined systems nor completely casual (Buiatti, 2008). The study of stochasticity and canalization or constraints in particular has demonstrated that living beings’ structures and functions and their personal history are always in between causality and randomness (Gould, Lewontin, 1979; Buiatti, 2006). And we could go be even more further specifying that in this new way of thinking nonetheless there is a choice to be made, nonetheless there is a tendency to a certain polarization, already in the choice of the object of analysis made by the scientist.

> L’oggetto che si osserva e’ in particolare di grande importanza per l’interpretazione dei dati ottenuti e soprattutto per l’elaborazione di leggi che dovrebbero riguardare la vita nel suo complesso. E’ abbastanza ovvio infatti che chi della vita, osserva solo molecole, ne ricava tendenzialmente una visione fortemente deterministica anche soltanto perche’ ha difficolta’ ad osservare le interazioni a livello superiore di organizzazione. (Buiatti, 2008, p. 67).

On the contrary approaches that are more systemic such as considering ecosystems or biospheres is more used to a different selection in choosing the “unities of analysis” as we have called them with *GT*'s formula. As we will see in the conclusion there is a peculiar *Zeitgeist* for every theoretical selection. Watson and Crick were working on just one molecule, DNA, that for them became the center of life or Jacob and Monod had studied relatively simple organisms such as bacteria when attempting their mechanical theory (1961)[166]. While Waddington was an embriologist and a geneticist that was studying development and in his analyses put particular emphasis on the phenotipic traits[167].

> Questa frammentazione in diverse discipline, e in ognuna delle quali si elaboravano teorie locali ritenendole universali e' stata probabilmente una delle cause principali della tendenza a ragionare per antinomie rigide apparentemente non coinciliabili. Anche nel dibattito attuale di fatto si tende a contrappore caso a necessita' [...] controllo genetico ad effetti dell'ambiente nella determinazione della storia di vita, indipendenza e additivita' dei componenti dei sistemi biologici a strutture a rete ad interazioni non lineari, continuita' a discontinuita' dei processi. Buiatti (2008), p. 69.

3.

These researches on proliferation control can easily be approached also from the standpoint of carcinogenesis and neoplasia studies. Also the history of these genres of researches in fact showed a clear polarization between two main theories: a Somatic mutation theory and a more synthetic approach that was sustained in particular by S&S.

Neoplasia literally means "new growth" (from plasis "molding, formation" and from the ancient Greek verb *plassein* "to mold", see for instance the derivation of plasma).

Here we find a *meaning and naming question*, but not a nominal

[166] Jacob F. Monod J. (1961), "Genetic regulatory mechanisms in the synthesis of proteins". J. Mol. Biol. 3: 318–56.

[167] Waddington (1975) , The evolution of an evolutionist, Edinburgh University Press, Edinburgh; see also (Fox-Keller, 2002)

problem, as "definitions of neoplasia are plagued with problems that stem from our imperfect grasp of the biological process that underlies its genesis" (Ivi, p. 91). Let us start then with some clarifications.
Tumors, according to their behavior studied by physicians in patients, have been divided into two categories: malignant and benign.

Benign tumors	**Malignant tumors**
circumscribed, often separated from the adjacent normal tissues by a capsule	develop invasively into adjacent tissues
expansion is slow	give rise to secondary tumors (metastases) in distant organs and recur either locally or at distance from primary location
not life-threatening	life-threatening

Figure 3. Traditional scheme of malignant tumors versus benign tumors.

Benign tumors are circumscribed, often separated from the adjacent normal tissues by a capsule, their expansion is slow and frequently they are not life-threatening. While malignant tumors develop invasively into adjacent tissues, seldom giving rise to secondary tumors (metastases) even in distant organs. Even after treatment, malignant tumors frequently recur locally as well as also at distance from primary location. They may bring the patient to death.
Normally neoplasias are defined according to the tissue source from which they derive, thus their nomenclature is neutral on etiological meaning.

Benign neoplasias	Malignant neoplasias
Epithelial origin: *adenoma* (gland-like structures) or *papilloma* (wart-like structures)	Epithelial origin: *carcinoma*
Connective tissues: *fibroma* (fibrous tissue), *osteoma* (from bone), ...	Connective tissues: *fibrosarcoma, osteosarcoma*, ...

Figure 4. Traditional scheme of malignant neoplasia versus benign neoplasia.

It is very interesting to remark that since the late 19th century till now the light microscope has always been the elected instrument to analyze cancer tissues. In a sense this enlightens, as S&S remark, that cancer research is a particular domain where the expectation of an impact of molecular biology revolution has not been realized, confirming that the hierarchical level or, as we have learned from *GT*'s lecture, the proper unity of analysis for cancer recognition is *tissue*. This a very important statement of S&S's analyses.

> This simple realization stealthily suggests that *tissue disorganization* is at the core of carcinogenesis and neoplasia (Ivi, p. 92).

Keeping this very important notion from S&S's hypothesis about the origin of carcinogenesis and neoplasia, we may need to resume some characteristics of cell differentiation before going further on. First of all differentiation is a characteristic proper to all cells in multicellular organisms. The notion that *only cells that are undifferentiated proliferate is thus mainly incorrect* (Ivi, p. 78 see Darnell, Lodish, Baltimore, 1986). This kind of misunderstanding is at the base of some controversial matters.

- differentiation deals with how the diverse 'specialized' cell types in an organism are derived from a single cell. Differentiation may be considered thus as a relative and qualitative concept.
- thus opposed to a quantitative description, which for instance means that one cell type such as fibroblast, is morphologically and functionally less differentiated than a nerve cell.
- the process of self-renewal by stem cells in adult tissues is also a differentiation matter. In this case and only in it, differentiation becomes a quantitative and hierarchical process: stem cells mother, unable to perform the function of a particular tissue generate cells that progressively differentiate into a fully functional cell[168].

The phenomenon of "demergence" may take place when *in-culture* cells from metazoa show properties that do not appear at the organismal, organ or tissue levels. As an effect of a collapsing of the boundaries or constraints of the hierarchical organism organization cell *in-culture* may reacquire their ancestral properties, including proliferation and mobility (Ivi, p. 80).

> Tissue self-renewal may occur as a result of the proliferation of functional differentiated cells in some organs, and of stem cells in others. Hence there is no univocal relation between proliferation and differentiation. Cell proliferation and differentiation are biological phenomena that are best analyzed by dissociating them conceptually (Ivi, p. 87).

However, the concept of "differentiation" was used by pathologist to denote the degree of deviation found between the architecture of the neoplasia and that of the normal tissue from which it presumably arose. This gave a simple correlation:

- the closer to the normal tissue, the more 'differentiated' the tumor is considered

[168] For an accurate description of stem cells and their different types (totipotential, pluripotential and monopotential) see S&S, 1999, p. 79- 80.

- conversely tumors that are less similar to the tissue of origin are called ‘anaplastic’ or ‘undifferentiated’ (p. 92)

Like every other tissues also neoplasias contain a *parenchyma* (the distinctive cell type of an organ) and a supporting tissue or *stroma* (the scaffolding to which *parenchyma* cells are attached). All tissues require a normal architecture where *parenchymal* and *stromal* cells operate in a complementary way (Ivi, p. 92). It is interesting to notice that as an evidence metastases often reproduce the structure of the primary tumor, suggesting that neoplastic cells that migrate through blood and lymph are able to recreate the tissue of origin far away from it.
Having cleared some points about differentiation we may go back to the evidence that *tissue disorganization is at the center of the analysis of carcinoma and neoplasia*. Now the question that arises is how do neoplasias start to develop?
Environmental agents (such as chimney sweeps, asbestos, burnt and all new synthetic chemicals) have been under the eyes of pathologist since 18th century, microbes and “filtrable factors” (viruses) are considered responsible respectively of neoplasias transplantation and occurrence. Tumors appearance have been observed in many different multicellular species, showing that neoplastic development is possible in all metazoa.
As we said, metastases are able to reproduce the structure of the primary tumor, suggesting that “parenchymal cells carry in themselves *all the information* necessary to form a tumor” (Ivi, p. 93). It is very important to remark here the interpretation of the interaction model studied. It is evident that the main idea is that of an information carried that contaminates by spreading thus, communicating, or inserting by force a signal or a deviation command into the receptive tissue, *activity* which seems rather *passive*. The fact is that every common *metaphor of lock and key* or active signal and passive receptor organ, and so on, are all recalling a reification of the process, rather than its explanation, as we have seen very often coming back in the history of the concept of interaction. In this case, if *neoplastic cells were able to bring themselves the signal of the release of a deviation, what kind of signal-change occurred in the normal cells that made them becoming neoplastic?*
The answer that S&S propose is that the notion of mutation was a

quite at hand supply for this question.

> Mutation is derived from the latin world for change. Hence it was proposed that a neoplastic cell resulted from a 'mutated' normal cell. The usage of the word mutation has changed since then; today it means a change in the linear structure of DNA. The *somatic mutation theory*, the currently prevalent theory of carcino-genesis, is based on this assumption (Ivi, p. 94).

Here we arrive to touch one of the central questions of S&S's researches. The point is whether it is necessary to invoke genomic mutations to explain neoplastic ontogenesis.
Let us close putting together two main data:

- all adult human cells contain the same data, for instance the DNA of a liver cell is identical to the DNA in a kidney cell of the same individual
- *somatic* cells contains all data needed to develop a whole animal
- a change in the behavior of a cell (phenotype) does not necessarily require a change of the the structure of its DNA (genotype), rather a change in the repertory of genes being expressed (epigenesis) (Ivi, p. 94).

A consequence of this is that the somatic mutation and epigenetic theories provide alternative ways of explaining the stability of the phenotype of neoplastic cells (Ibidem). Some other evidences brought pathologist to stress that all the properties of neoplasms (mentioned in the table above) could be found also in normal cells, thus a general question was standing out: is there something like a sort of essence of neoplasia or rather should it be considered as an emergent phenomenon deriving from a deficiency among cells and their interactions in tissues? The experiments on animal highlighted again two opposed approaches: one that was reductionist which adopted the premise that the deviation from normalcy was a "cellular phenomenon caused by mutations" (Ibidem), and another which put into light "the subtle changes in tissue organization that preceded the established of the neoplasia" which is an integrative approach (Ibidem).

> Those following the integrative approach, a minority, thought that since tissue organization was altered, carcinogenesis was due to

> the disruption of communications among cells and tissues. In short, carcinogenesis was interpreted as a cellular and mutational phenomenon by some, and as an integrative phenomenon involving *disruptive interactions* among cells and tissues by others (Ivi, p. 94-5, our italics).

We have to underline now some main points about germ-line mutations and carcinogenesis which are at the center of the somatic mutation theory. In fact a certain cancer frequency has been observed into same families, anyhow S&S underline that there is no evidence by now of the manner in which this germ-line mutation would directly affect the somatic cells turning them into neoplastic (p. 25). Thus one finds again in a double opened horizon: whether there is a direct or indirect correlation between germ-line mutation and the developing of the tumor phenotype. In the case of the indirect determination one would rather consider that the gene which is mutated *interacts and interferes with the organizational processes at the hierarchical level of tissues*. We can recognize at once in these two standpoints the two opposite points of view that we have put into light about the concept of interaction, a deterministic-elementary and a complex-organic.

To resume, one should state that in the last sixty years many difficulties have been underlined about the explanation of germ-line mutation direct responsibility for neoplasia development, among them two main points should be considered. From one side somatic mutation theory is not able to foresee the neoplastic phenotype of mutations, while on the other side the explanation core is the correlation between mutation and cells proliferation dysfunction; but one should straightforward highlight that the rate of neoplasma cell proliferation is not higher than normal tissues. While for instance the "proliferation rate of cells in neoplasms of hormone-target organs is susceptible to the hormonal milieu in the host" (ivi, p. 96). For example, breast and prostate neoplasms regress when their trophic hormones, estrogens and androgenes, respectively, are removed leading to the conclusion that neoplasms are not "essences" or entities, because such behaviors cannot be explained by mutations with *irreversible character169.*

But as a result of many different researches for over fifteen

[169] See for instance Pierce et al. (1978) on teratocarcinoma cells which highlights epigenetics mechanisms operating in control of differentiation.

years170, nonetheless cancer seems to rest in the main stream conscience and in ordinary one as “triumphant mutation” (Sontag, 1990, p. 68) by which tumors are “experienced as a form of demonic possession – tumors are malignant or benign, like forces” (Ivi, p. 69).

> The hypotheses that carcinogenesis is an error either in cell proliferation, cell death, or cell differentiation, or a combination of these three processes, still adopt the notion that mutations are causal agents, and that neoplasia is a cellular phenomenon (ivi.p. 97).

Therefore putting together so many conflicting and disappointing data one should come to the conclusion that the problem rather than collecting more facts and evidences is finding a way to interpret them:

> Experimental analysis has produced an alarming mass of empirical facts without providing an adequate language for their communication or effective concepts for their synthesis (Foulds L., 1969, *Neoplastic development*, Academic press, London, Preface)

In the years of the argument above few genes were known concerning the cell cycle control, as well as the receptors and the factors that controlled genetically which activity could activate or stimulate cellular division or cellular block. The genetic regulatory model was the Jacob-Monod lactose operon. The homeotic genes of Drosophila were known and mapped, but nobody was hypothesizing the possibility that those genes could be present in all the higher eukariots for the control of the body plan. The frame of researches has changed a lot, showing a more complex multi factorial net of interactions such as cell signaling pathways, epigenetics and regulation mechanism (Plotnikov A., Zehorai E., Procaccia S., Seger R., 2010, “The MAPK cascades: signaling components, nuclear roles and mechanisms of nuclear translocation”, *Biochim. Biophys.*

[170] Farber E. (1995) “Cell proliferation as major risk factor for cancer: a concept of doubtful validity”, *Cancer Res.*, 55: 3759-3762; Harris H. (1995), *The cells of the body: a history of somatic cells genetics*, Cold Spring Harbor laboratory Press, Plainview, NY.

Acta, Dec 16; Buiatti, 2000; 2008; Jablonka, Lamb, 2006). Thus the need for an adequate language to use when interpreting experiments and in theorizing activity is increasing.

4.

S&S's proposal of proliferation as the default state of cells and of the hierarchical reference frame for treating organism, tissues and cells wants to give an account of a new language able to let things, facts, intuitions, "eyes of the senses" and "eyes of the reason" (Canguilhem, 1965) interplay together.
According to S&S there are four main hierarchical levels involved in cancer development which in a very similar way apply to animal or human disease:

- a *social level* which encompasses patient's clinical and social relations in a wide range (doctors, family, ...)
- *organismal level*, referring especially to the domain of the individual
- *organ/tissue hierarchical* level described under the light of the microscope
- *cellular/subcellular hierarchical* level in which neoplastic cells are described functionally with regards to their derivation from neoplasia present in the subject

While with this *hierarchical levels organization* one at least tries to take into account the major interactions involved in the complexity of cancer process, the approach developed by main stream research is homologue to that of elementariness in the study of cognition (see chapter one), which S&S name "cartesian strategy" (p. 101) and the conclusion is yet very similar to that which we have already put in evidence:

> In the process of "reducing" the object of analysis much has been learned about the parts, while the understanding of the whole has not fared so well (Ibidem)

We think that is also very interesting to remark the reversing of the traditional approach in the *hierarchical* level scheme by considering as first level that of social relations; we could say that in a sense this is the general point of view by which interpreting the theoretical "style" or assumption in the works by S&S. In this first social plan should be seen also all the epidemiological studies about environmental exposure, lifestyles, and heredity which has been called the "cancer industry" to mean altogether the sociological cause and effects of one of the most discussed ("obscene", Sontag, 1990, p. 9) and affecting disease of our occidental world (Fujimura, 1996; Proctor, 1995), a "demonic pregnancy" as it has been called (Sontag, 1990, p. 14)171.

I would like to particularly underline this point of view to look at S&S's approach because once one gets it all the rest follows. For instance a clear argument that sustains this hierarchical perspective is that prokariotes such as bacteria and unicellular eukaryotes such as yeast have never been found developing neoplasia, contrarily to multicellular organisms. Nonetheless surprisingly have been discovered in yeasts the paralog genes of the so-called oncogenes of the higher eukariots. It was demonstrated that all those genes were related to the control of the cell cycle and therefore conserved in all the eukariots. This was the reason why loss of control of these genes was associated with tumor progression in higher eukariots.

Moreover,

> The natural history of these carcinogenic processes has shown that they may either progress, not increase in size, or regress to normality (Clark, 1995). This multiple, diverging fate encouraged commentators to claim that cancer is not a single disease but many diseases (S&S, 1999, p. 102).

We have already mentioned the problem of the explanation of a degeneracy in the proliferation state of the cells, while there is not a direct evidence for this fact and we should add also another

[171] See (Sontag, 1990) for a beautiful and clever history of the metaphor of cancer transforming through years, gaining sexual and military valences and by which cancer is a disease which should be hidden from society and also from the patient: "All this lying to and by cancer patients is a measure of how much harder it has come in advanced industrial societies to come to terms with death", p. 8, and by which for instance immunologists class the body's cancer cells as "nonself", p. 67, or cancer as the "disease of the Other in a science fiction scenario: an invasion of 'alien' or 'mutant' cells, stronger than normal cells", p. 68.

peculiar trait underlined by S&S which is the connection made between cell motility (invasion) and development of a neoplasia state. Or in other words the fact that neoplastic cells enter lymph or blood vessels and migrate to other organs in the process named metastases. Both these characteristics (proliferation and motility) on the contrary are to be considered according to S&S as "built-in properties of all cells" [Buss, 1987] (Ivi, p. 102), thus not directly explaining neoplasia process.

Again here the question is radical: how should one consider neoplasia? As an entity or rather as a complex process involving many different and entangled levels of organization and in particular a flaw at the level of tissues' functioning? The most established point of view on the subject is an analytical-elementariness one to which one, recalling what we have already learned from *GT*, Hebb and Bernard, should add an isolated juxtaposition of elements in a *static* and not *dynamic* perspective of analysis. Therefore the idea is the description of a "static view" of advanced state neoplasia, thus already with its own evolution and history, resulting from a combined experience of histological pattern and the natural history of the disease, or in other words "the pattern read today is used to prognosticate, based on experience, what the most probable outcome will be in the future of a particular patient " (Ivi, p. 103).

One last data before going to look at S&S's tissue hierarchical level proposal is that no single cytoplasmic or nuclear attribute in any cell "is sufficient to unequivocally diagnose a neoplasia [Koss, 1992] (Ivi, p. 103), thus providing more insight for looking at different and more synthetic hypotheses.

Let us put S&S's puzzle together in a resuming scheme:

- normal adult multicellular organisms are built of discrete units of tissue maintenance and/or organization, from an histological point of view they are a functional part (parenchima) and the structural surrounding connective tissue (stroma).
- in embryogenesis adjacent epithelia and stroma interplay together giving birth to the organ formation in a complex network of signaling interactions which continue throughout the lifespan of the individual
- units of tissue maintenance and/or organization are structured tridimensionally and bring with themselves also positional (locality) and historical (dynamics) features, both anyway in an evolutionary meaning

- these units are present in all organs and are the ultimate targets of carcinogenesis agents
- teratogenesis, developmental tumors and "spontaneous" (the question is always that of spontaneous "alien" mutation) and induced carcinogenesis occur because of miscommunication among cells and tissues
- in "spontaneous" and agent-mediated carcinogenesis there is a flaw of the normal interactions that underpins cells parenchyma and subjacent stroma of an organ which emerge also at a functional and structural level in the affected tissue or organ
- a characteristic positional system of recognition is at work in individual cells which for instance allow cells in the parenchyma in increasing their proliferation rate (*hyperplasia*) and/or show the two-trait *dysplasia* which undermine the normal level of tissue organization increasing the production of new cells
- other kind of malfunctioning are *metaplasias* which are tissue type changing, for instance from simple cuboidal to stratified squamous epithelia, and seldom occurring at the border/junction between two different tissues, such as esophagus with stomach
- then typically two things happen; either a self-evident state of disruption called *carcinoma in situ*, or a *reversion* of the damaged tissue into a normal architecture and cellular phenotype (see figure 3).

This is the general plan of the induction or triggering of the neoplasia, the *Somatic Mutation Theory* (SMT) on the contrary has proposed for over a century that the hierarchical level interested is cellular and subcellular. Thus the SMT proposes that by means of one or some mutations on the genome of a somatic normal cell, the control cells proliferation is affected and consequently the cell becomes a neoplastic cell. S&S explicit the hidden assumption in this hypothesis: the default state of metazoan cells is *quiescence*, therefore mutations that trigger the neoplasia development are of the "gain-of-function" type, thus producing an increasing activity of cells proliferation, which have been called in fact *oncogenes* (e.g. Glover, Hames, 1989). The counterpart on the other hand are "loss-of-function" mutations which inactivate inhibitory signals coded by anti-oncogenes, which S&S remark to be one of the more significantly "ad-hoc addition" assumption of SMT (p. 105). A consequence of this is that *mutated oncogenes code for growth factors* and all the mechanisms involved in their functioning as we have discussed above, thus in a phrase:

> The products of these mutated oncogenes would stimulate cells stuck in *quiescence* to proliferate and, thus, generate a tumor [Alberts et. al., 1994] (Ivi. p. 106)".

It is just in the beginning of the eighties that researchers more considerably started to question the proposed *direct effect* of physical and chemical carcinogenesis on the "transformations" in culture due to mutational events (Kennedy et. al., 1980; Little, 1994) and even more significantly some evidence have shown how the transformed abnormal cells could be reverted to normalcy by just modifying culture conditions (Paquette, Wagner, Little, 1996; Rubin, 1992).

> These data suggested, instead, that transformation was a *hereditary, epigenetic, highly variable phenomenon* [...] Rubin and associates coined the term 'progressive state selection' to characterize this in-culture based phenomenon [Rubin, Sneade-Koenig, Rubin, 1992] (ivi, p. 107, our italics).

I have given emphasis with italics to the concepts that involve a dynamics and historical characterization opposed to a static and universal one in which it is easily possible to recognize the two main point of view concerning the concept of interaction which are we dealing with. It is known since the end of the '80s that the tumor progression is not limited to one single event and neither to one single mutation but is associated to a wide number of functions controlled by the interaction and expression of genes and relative proteins and enzymes generating and controlling pathways leading to cell life control and cell cycle. The genes involved can produce either positive or negative control of other genes or functions through intra cellular or intercellular interactions secreting factors that can interact with the receptors of other cells and cross-talk with other cells and tissues. It is clear that all can happen with inhibitory or stimulatory mechanisms.

Another interesting that S&S clearly put in evidence is a strong paradox, again in the in vivo and in culture results, in fact none of the transformation experiments *in culture* recapitulated the history that we have highlighted in the scheme above (hyperplasia, dysplasia, metaplasia and carcinoma *in situ*) occurring in animal at

the tissue level of hierarchical complexity, leading to the assumption that once detached from their level of organization they are no more responding to the same effects. Or even more astonishingly the *dissociation of tissues* may itself generates neoplasia by
"merely freeing cells from their *in situ* positional constraints"
(Ivi, p. 107).

> This in culture approach does not reproduce organismal phenomena. It represents, instead, an artifact equivalent to reversing the evolutionary process (from metazoa to unicellularity) (Ivi., p. 107).

We can say that in fact this result with the supposition of quiescence as cells default state goes together in a unique perspective which is not respectful of the hierarchical level of organizational process of the organism (molar) in its whole to unit or global to local interactions, rather this approach focus on an idea which is based on elementariness, detached from environmental and contextual dependencies (molecular), or in a nutshell is not result of a procedural methodological-theoretical correspondence. As S&S propose in a metaphor is such as hoping to reconstruct the flux of a traffic jam in a particular time in a particular position everyday by summing all the trajectories, accelerating, braking, steering, that the drivers have made.
Here we have more or less put our hands onto the main problem and on the principal differences between the two approaches to cancer development (SMT and S&S's and others' account for a flaw in the hierarchical organization of the tissue). By now we should try to figure it out some explanations of the implicit motivation for those oppositions to have come out, or in other words the rationale underneath the two proposals. S&S hint to look at a more general opposition between a mechanical (physicalist-mechanicist) and a vitalist (epigenesis) point of view. We can see here a profound correspondence with what we have already observed in previous sections, so we should not insist on that. But from this more peculiar point of view we should underline that the mutation explanation of neoplasia given by Boveri in 1914 described the production of an "abnormal mitosis" which propagates their abnormality among all cells daughters through chromosome inheritance factors (Boveri T., 1929, *The origin of malignant*

tumors, Williams and Wilkins, Baltimora, MD). Then the discovery of DNA double helix structure put in evidence the peculiar molecular explanation of the transmission of genetic information from mother to daughter cells, thus providing also the mulecular-genetic basis for SMT (carcinogenes, or oncogenes). The main question that was underlined nonetheless is "how do carcinogenes disrupt the 'inheritance factors' of Boveri, or the genes of the geneticists, to produce neoplasia?" (Ivi, p. 114). From the evidence later on discovered that some carcinogenes are mutagenes while others are not (Miller & Miller, 1977), two main problems which are yet opened arisen :

- how could be the mutations the necessary direct cause of cancer development?
- which gene(s) has to be mutated to produce a histological lesion with the physical and behavioral characteristic of a neoplasia? (Ivi, p. 115)

On the other side some of the vitalist ideas were rather encompassed in a new paradigm, focusing on organism development. From this standpoint while at a molecular level biological phenomena could be described by means of physic-chemistry laws, at higher levels of organization such as tissue, organs, individuals and so on there were some emergent and integrative phenomena that *could not be explained directly* in physico-chemical terms (Ivi, p. 114).

> Following this rationale the concept that carcinogenesis is an emergent phenomenon resulting from abnormal tissue organization could not be formulated until embryologists created the concepts of organizers and morphogens to explain embryonal development; these concepts were established in the 1920s and 30s, mainly trough the efforts of Spemann (Ivi, p. 114)172.

Thus again we can sum up that "despite the intensity of human and material resources that have been focused on cancer *per se*, the essential biochemical and genetic basis for the different major

[172] Hans Spemann's works (*Embryonic development and induction*, Yale Univ. Press, New Haven, 1938) were mostly concerning the phenomenon of embryonic induction (Nobel Prize in Physiology or Medicine in 1935) by which he observed some influences of different parts of the embryo called "organizers", which canalized the development of populations of cells thus forming particular tissues and organs. For a reconstruction and a detailed discussion also on the previous Roux's and Driesch's experiments on the subject see Cavazzini, 2009.

properties of cancers, such as autonomy of growth, invasion and metastasis, continue to elude the cancers researchers" (Farber, 1984, "Chemical carcinogenesis: a current biological perspective", *Carcinogenesis*, 5, pp 1-5). There are different observations about neoplasia onset's causes that S&S have put in evidence concerning foreign-body (Brand, 1982; S&S, 1999, p. 118-119), physical (Kern, 1996; S&S, 1999, p. 120) and chemical carcinogenesis experiments (Miller, Miller, 1977; S&S, 1999, p. 120-1). In all these cases there are evidence and counter evidence that could be summed up in an astonishing sentence by 1966 Nobel Prize's winner Peyton Rous:

> A favorite explanation has been that (carcinogenes) cause alterations in the genes of cells in the body, somatic mutations, as they are termed. But, numerous facts, when taken together decisively exclude this supposition (Rous, 1966 cit. in S&S, 1999, p. 121-2).

It is utile to remark then that nonetheless major investments and technological advancement it is still not possible to observe the very first origin state of neoplasia, and the same set of evidences could possibly be explained differently depending on a priori assumptions that different scientists adopt (Ivi, p. 126-7). Because as S&S frequently suggest "data are never theory-free" (p. 118) and rather are frequently chosen for their consistency with the theory a priori chosen. As we said this is an integral part of science theory-laden construction which is in fact always a result of a mix of data, facts, interpretations, assumptions, creeds,... (Amzallag, 2002). Nonetheless this a priori decision for a theory which is necessarily also a personal commitment, as we have said, should never be transformed in a dogmatic attitude or as Amzallag provocatively calls it "enthusiasm" or "faith".

> Biologists deal with operational definitions out of necessity, since we are piercing into a black box that we have not designed, and therefore, we can hardly second guess. When exploring a given phenomenon, there is a lot more than meets the eye. However everything that goes into the black box and produces an effect is anthropocentrically interpreted as a "stimulus", an "inducer" or a "positive regulator". If instead, what goes into the black box prevents the occurrence of a phenomenon that would have taken place without our intervention, the modifier becomes a "blocker", a "repressor", or a "negative regulator" (Ivi., p. 136).

S&S suggest that these usages are acceptable as long as one recognizes that they are all operational criteria and not real, entities phenomena, which should then also remark our intervention in the matter just as a proximate cause, and not a direct explanation. As we said this is a quite common attitude which reificate concepts and models establishing their essentialist reality rather than their procedural functioning.
There is also one major and fundamental distinction between the two theories that should be underlined. While in the SMT perspective *in culture* results are interpreted as legitimate experimental models because it does not consider a higher level than the cellular one, on the opposite side, from tissue organization field theory's standpoint there are two different approaches to in culture experiments:

1. establish the ineffectiveness of in culture cell experiments as they are unable to offer an analysis of carcinogenesis initial triggering such as seen in animals
2. in culture mutated cells are equivalent to neoplastic in animals cells which arose from a process which nonetheless does not recapitulate carcinogenesis (as we have highlighted). A state of "demergence" in culture removes the constraints imposed in the organism *milieu* (Earle, 1943; Gey, 1955; Sanford, 1965; Rubin, 1985; Paquette, Wagner, Little, 1996)

Thus one have to remark than according to tissue organization field theory's standpoint in culture experiments apt are only those which preserve the hierarchical level of tissue as a model, which is very limited nowadays in reason of the very precarious lifespan of explants (Ivi, p. 128). One experiment starts always from an "a priori" to answer a question or to demonstrate one hypothesis. The investigator has then to interpret the results and thus he should also think about the a priori assumptions that he has made: if the premises were wrong the hypothesis must be changed.

> This is a book about concepts, data, and interpretations. Throughout its chapters, we have contended that the understanding of control of cell proliferation and cancer has been hindered by unstated ideologies and operational definitions. We hope that our analysis has persuaded you, the reader, of the importance for unveiling hidden premises chosen by researchers when designing

> experiments and interpreting data. Because premises cannot be avoided, they must be acknowledged and dealt with up front (Ivi, p. 134).

5.

We recognize here in this discussion both ideas that we have already underlined concerning the concept of interaction. On one side the fact that its understanding passes from delineating and make explicit a hidden history which is a mix of practical and theoretical evolutions or “exaptations” and on the other side that starting from different premises one refers to the concept of interaction in a physico-mechanical way or rather in an organical-gestaltic approach. And this choice is always a commitment as well as a possible dogmatic tendency.

> Ou plus exactement, les faits suscitent les théories mais ils n'engendrent pas les concepts qui les unifient intérieurement ni les intentions intellectuelles qu'elles développent. Ces intentions viennent de loin, ces concepts sont en petit nombre et c'est pourquoi les thèmes théoriques survivent à leur destruction apparente qu'une polémique et une réfutation se flattent d'avoir obtenue (Canguilhem, 1965, p. 100)

But, then, where do these ideas used as premises of cell theorization come from?
To go further in the explanation of these two typical and opposed visions also in biological field, which as mentioned above are a reflex of a more general dispute between an analytical and a synthetic point of view, we may look at the context that has generated them. Or referring to James’ metaphor in previous section, we should see where the division line has been traced and in the name of which conception. We would sketch this ground context of the germination of biological theories and of the theoretical standpoints emerging from them, in particular the conception of the cell theory commented by Canguilhem.
One issue among the various interesting things that Canguilhem has clearly put in evidence in his life sciences’ studies is that there is an important characteristic which distinguishes specifically the

domain of biology: it is *in between* proper experimental sciences and theoretical or rational ones. One of the most clear example of that is the discovery of the "unit of life", the cell, which is at the frontier between a technical development (the microscope) "les yeux de la raison" (that sees the light waves, in Canguilhem's words) and a purely sensible-observation with "les yeux organes de sens".
Therefore we will start to see which are some traits of the ground of the cell theory and its further stakes. In the middle of this frontier between meanings and different approaches is very important to remark with Canguilhem that

> La théorie cellulaire ce n'est pas l'affirmation que l'être se compose de cellules, mais d'abord que la cellule est le seul composant de tous les êtres vivants, et ensuite que toute cellule provient d'une cellule préexistante.

This remark puts in evidence two things at the same time:

1. firstly the accent is not on the cell as components, thus hinting the elementariness but rather on the universal homologue characteristic of the cell for all living beings.
2. secondly that a cell comes from nothing but a cell

This second statement is what the Belgian botanist Barthélemy Charles Joseph Dumortrier explained in 1832 in his book *Recherches sur la structure comparée et le développement des animaux et des végétaux* (M. Hayez ed.). He describes the cell division process he had observed as the fundamental biological idea for which cells only originate from cells. In the Section III of the book, named "Structure et developpement des animaux", at the beginning of the first paragraph "Lois du Développement" there is this excerpt, very original and thoughtful:

> AUTANT les deux règnes des corps organiques sont distincts dans leurs extrêmes, autant ils se confondent lorsque l'on arrive aux êtres les plus simples et les plus imparfaits. La différence des animaux et des végétaux, si sensible aux extrémités de la chaîne, devient enfin presqu'inappréciable et les corps organisés, d'abord essentiellement différens, finissent par se confondre et par rentrer dans un seul et même type. Il semble que la nature, en parcourant deux routes opposées, ait voulu partir du même principe.

> (Dumortrier, 1832, p. 57).

We should immediately underline this remarkable conception of an inversion of criteria in the macroscopic and in the microscopic world. While macroscopically we undoubtedly conceive all the distinctions between animals and plants and also between different species, when we approach the world from a microscopic point of view we have to remark an undeniable homology. We may hint an analogy with the emergency characteristic that Lucretius suggested about looking at sheeps the perception of which at distance is completely vague and indistinct, while becoming nearer it allows to distinguish properly the collection of the elements-sheep (see chapter one). If on one hand we are supposed to assess that animals are in a higher level of the hierarchical ladder than plants ("aux extrémités de la chaîne") as it was considered at Dumortrier's time and still is frequently considered nowadays, conversely Dumortrier states with astonishment that this law is no longer valid at the microscopical level. Bodies get to be confused among each other and become *one* and *only* type. He adds something even more theoretical, the nature, he says, that moves towards two opposed routes seems to have got started with the same principle! This idea is thus at the basis of Dumortrier conception of the cell.

> En effet, la monade qui n'est pour ainsi dire qu'une cellule vivante, est le point de contact de deux embranchemens dont l'un suit la loi de l'animalité et l'autre celle de la végétation. Vivre et se reproduire est la condition indispensable du règne organique, et la reproduction est aussi essentielle à la conservation de l'espèce que la vie à celle des individus. La reproduction est le résultat de la divisibilité, la vie est un mouvement limité par le corps. (Ivi, p. 57-58)

I want to underline two facts mentioned in the quote that we should remark that is of year *1832*:

(1) to live and to reproduce are the same indispensable conditions both for specie and individuals

(2) reproduction is the result of divisibility

Now it is accepted that divisibility is *necessary but not sufficient* for reproduction as in the case of cell differentiation were the division does not reproduce the same cell type because after the division one can find cells that are different from the cell mother. I remark nonetheless in this commentary of 1832 the main idea by which it is highlighted the strong connection of cells with life and generation of life. The cell is the fundamental component of living beings, a sort of basal structure and the entire organism architecture is made by the active division of a cell into two cells. I think it is useful here to note this *active* declination of the *process of cell division* which is also the underpinning of the propagation and of the pervasive power of life.

> La théorie cellulaire serait alors un recueil de protocoles d'observation. L'oeil armé du microscope voit le vivant macroscopique composé de cellules comme l'oeil nu voit le vivant macroscopique composant de la biosphère. Et pourtant, le microscope est plutôt le prolongement de l'intelligence que le prolongement de la vue. Canguilhem (2003), p. 59.

Thanks to the microscope's help one may distinguish two different macroscopic world: the one made up of cells and another which is the biosphere context of individuals. In the distinction made by Mayr one may say that both are part of the *mesoscopic* world proper to biological analysis, rather than the microscopic world which is domain of quantum physics and macroscopic which is the object of cosmology and the study of the universe (Mayr, 2000). But Canguilhem wants us to understand a more subtle peculiarity of biological investigations. Here the tool is not only a technical device, but more properly a tool of the reason, according also with Vygotskyan expression we have highlighted. Canguilhem puts in evidence the hiatus between the meaning of "seeing with the eyes of the reason" and that of "seeing with senses", between sense and sensibility, reason and intuition and so on, which are nonetheless both constitutive and interwoven elements of scientific research.

> Or cela ce n'est pas le microscope qui autorise à le dire. Le microscope est tout au plus un des moyens de le vérifier quand on l'a dit. Mais d'où est venue l'idée de le dire avant de le vérifier ? C'est ici que l'histoire de la formation du concept de

cellule son importance. (Ibidem).

Canguilhem puts magnificently in evidence the problem of the distinction of a proof in biology. Theories are not necessarily made by technique; a biologist is put in the condition of elaborating an hypothesis not necessarily by means of a result, on the contrary the quest for evidence is something someone decides to look at just after an intuition for such hypothesis. This same idea of asking *why* and which is the origin of some main concepts or guardrails in science is also very important in S&S's standpoint. It is relevant for our discussion to better connect experimental procedures used in cell proliferation experiments with the rational-theoretical insight to catch the underpinning ideas and clarify a bit more the opposed hypothesis they support.
As we see here it emerges also something that is at the center of our investigation about the concept of interaction. When one from the level of cells includes in the horizon of research also living beings' complexity and the questions arising from the observation of the individual as a whole (moreover made by living beings themselves) it becomes impossible to consider them just as if they were in their *atomic-elementary* consistence. The interaction per se unfolds its polarity frame: once one observes an interaction it opens the friction between the objects of observation and at the same time the interference and the possibility of a deferment (which are all constitutive elements of research, and not futile or adds-on). We have already seen the importance of the obstacles for the enhancement of science in Bachelard's words in the opening quotation by Canguilhem[173]:

> Il peut donc être profitable de chercher les éléments d'une conception de la science et même d'une méthode de culture dans l'histoire des sciences entendue comme une psychologie de la conquête progressive des notions dans leur contenu actuel, comme une mise en forme de généalogies logiques et, pour employer une expression de M. Bachelard, comme un recensement des «**obstacles épistémologiques**» surmontés ! (Canguilhelm, 1952)

Remarking this inevitable and paradoxical way of the achievement

[173] See also Longo's commentary on the importance of negative results in science (Longo, 2008).

of scientific researches, which as we have already seen has been at the basis also of S&S's research developments, it is important now to look more in detail at the philosophical insight of cell theory to understand the *worthinesses*, the established *creeds* and the *stakes* it carries which not necessary are so explicit.
As it seldom happens in the history of the thought and in science[174] there are attributions of discoveries which might be not exact, for instance despite Dumortrier's discoveries to which we made reference S&S underlines that it is

> Generally recognized that the father of the cell theory was Schwann, who suggested in 1839 that cells both in animals and plants were their building blocks, explicitly locating all functions of living organisms within these units (Sonnenschein, Soto, 1999, p. 2).

As it has already been noticed for instance by Canguilhem's lecture about the origin of the concept of reflex that seldom the problem is hidden under a nominative appearance (Canguilhem, 1955). Nominative attributions together with dominance effects extend the prevailing ideas over time and epochs, creating a specific *Zeitgeist* that once in action is very difficult to detached both from the eyes of the reason and from the eyes of the senses. What concerns us here in fact is barely the opposite of a pure nominal debate, rather it is a conceptual strive.

> L'obstacle à une théorie n'est pas moins important à considérer, pour comprendre l'avenir de la théorie, que la tendance même de la théorie. Mais c'est par sa tendance qu'une théorie commence de créer l'atmosphère intellectuelle d'une génération de chercheurs. Canguilhem (1965), p. 62.

The term "tendency" is what here we need to take into account. Canguilhem considers that there is a very little number of ideas in

---

[174] It is interesting for instance what Canguilhem himself writes about the often supported Hook's discovery of and naming of the cell. "Concernant la cellule, on fait généralement trop grand honneur à Hooke. Certes c'est bien lui qui découvre la chose, un peu par hasard et par le jeu d'une curiosité amusée des premières révélations du microscope. Ayant pratiqué une coupe fine dans un morceau de liège, Hooke en observe la structure cloisonnée. C'est bien lui aussi qui invente le mot, sous l'empire d'une image, par assimilation de l'objet végétal à un rayon de miel, oeuvre d'animal, elle-même assimilée à une oeuvre humaine, car une cellule c'est une petite chambre. Mais la découverte de Hooke n'amorce rien, n'est pot un point de départ. Le mot même se perd et ne sera retrouvé qu'un siècle après", Ivi, p. 59-60.

science that constantly recall back the one with the other and not necessarily with regards to the same subjects of knowledge: for instance describing different objects, disciplines and points of view. According to Canguilhem, we could refer to these ideas as *constant ways of thinking* ("modes de penser constants") which are constitutive parts of science explanation.

> Nous devons dire, contre le lieu commun empiriste, souvent adopté sans critique par les savants lorsqu'ils s'élèvent jusqu'à la philosophie de leur savoir expérimental, que **les théories ne procèdent jamais des faits**. Les théories ne procèdent que de théories antérieures souvent très anciennes. Les faits ne sont que la voie, rarement droite, par laquelle les théories procèdent les unes des autres. Ibidem.

Now starting from these precious remarks, if we concretely observe the years in which the experiments about cell and cell life received a technical improvement one may find some traces of these constant ways of thinking that enabled to create a particular *Zeitgeist concerning* cells functioning and cell theory. We could then put in evidence and better comprehend some characteristics which we have already noticed in the discussion about cell proliferation.
As we observed the emergence of the radioactive tracers in the years '50 permitted many different improvement in the research. The year 1953 in which for instance cell cycle was described in the roots of fava beans is signed by many different events, at least two are very relevant for our discussion, but we find it interesting to mention also some contextual circumstances because as we are more and more understanding in this field there are no facts that can be detached from their *ground*, or avoiding the eyes of the reason while observing with the eyes of the senses. Quoting a remark made by Lassègue[175], which concerns cognitive science domain, but which I find very useful and appropriate for our commentary:

> As a science of the *mind*, cognitive science should be able to describe (and hopefully explain) what is going on in the mind, especially the way *individuals* manage to create new concepts which must be worked out by real human beings. (Lassègue J.,

[175] It is a response to Leiber's critics on Lassègues article "What Kind of Turing Test did Turing have in Mind?", On My Vicious Ways. A Response to Justin Leiber", *Issue 3 response, Tekhnema,* 6 / Fall 2000.

"On My Vicious Ways. A Response to Justin Leiber", *Issue 3 response, Tekhnema,* 6 / Fall 2000).

Here again the accent is on the environmental-cultural influences, which, as we have often remarked are not only proximate causes, but rather constitutive part of the development of research and the creation of new ideas. Moreover Lassègue puts emphasis on the materiality of the minds, critic which seems to recall the Universal Subject issue that we have already found operating as a traditional and established approach to cognition. Thus we could try to give an overview on some of the main ideas that were passing by *the minds* of that epoch, trying to figure it out *in our minds* how and which *new* concepts were emerging from this context.

The first event we should mention is the discovery of the chemical structure in double helix of DNA by Francis Crick, a British physicist and James D. Watson, an American biologist who published on April the 25th in the journal *Nature* the article "Molecular structure of nucleic acids: a structure for deoxyribose nucleic acid". The second is Howard and Pelc's description of the cell cycle in the roots of fava beans[176]. "This generated a wave of research on cell cycle kinetics in normal and cancer tissues and mammalian cells in culture" (S&S, 1999, p. 8). These kinds of issues brought to define cell cycle properly, as we will see, but we may make a brief stop and consider some other events that took place in 1953 that will allow us to represent *in our minds* the context and the tendencies of that epoch.

In the same year, Alan Turing, one year before his death, published "Some calculations of the Riemann zeta-function"177 in which he describes the first 1,104 zeroes of the Riemann zeta-function, a fundamental problem in number theory in which computers application started to show its results[178]. As we read from Lassègue:

[176] Howard A., Pelc S.R., Synthesis of DNA in normal and irradiated cells and its relation to chromosome breakage, Heredity (Suppl.), 6, p. 261-273.

[177] Proceedings of the London Mathematical Society. Third Series 3:99--117, 1953.

[178] Previous results concerning Riemann zeta function were proposed by L. Euler in the eighteenth century. But it took its name after B. Riemann, who in the dissertation "On the Number of Primes Less Than a Given Magnitude", published in 1859, found a relation between the zeros of the function and the distribution of prime numbers. It is relevant to notice that in the same paper one finds the "Riemann hypothesis" about the distribution of complex zeros of the Riemann zeta function, which in pure mathematics is considered one of the most important unsolved problem.

> Since his sabbatical year of 1947-1948, Turing became more and more involved in theoretical biology. He finally wrote an article, published in 1952, which was considered by him as having the same value for biology as his 1936 article for computability. In this article, he builds a mathematical model of a specific biological reaction for which he planned the future use of computer simulation. But why was he so preoccupied by morphogenesis? After all, he did also pioneering computer simulation in a field which was much more familiar to him as a mathematician, the computation of the Riemann zeta function. Why morphogenesis then? (Ivi)

In fact why morphogenesis? We will try to see a possible answer later on putting together the elements we are gathering. For the moment, I find it interesting that at the same time in which Turing was improving computer simulation on the computation of the Riemann zeta function, he was also developing very interesting ideas on morphogenesis, and that at the same time DNA structure was described and the cell cycle was studied more and more significantly. One may add that in the very same year the *IBM* industry was opening to the computer science market with the computer model *IBM 701* and that on March the 3rd the first microfilm were shoved in a newspaper before the Photographic Society of London and in Autumn they were exhibited for the first time in Paris179.

It should not surprise us that in this climate in between technical supplies and great biological discoveries hybrid ideas were spreading and diffusing around. In Carnap's text of the same year "Testability and Meaning"180, a revisited edition of its 1936 book *Philosophy of science*, for instance he distanced himself from the philosophical position of Logical positivism in particular with respect to hard science, emphasizing the idea of gradual accumulation of many small results in science. And *Science and Human Behavior*, the capital book by B. F. Skinner, the father of behaviorism to which we have previously make reference, appeared

[179] 1839 January 7: Announcement made to the French Academy of Sciences that Daguerre has perfected a practical method of photography named the daguerrotype. And in the same year Dancer makes first microphotograph on a daguerrotype plate at 160X reduction. From "CHRONOLOGY OF MICROFILM DEVELOPMENTS" http://www.srlf.ucla.edu/exhibit/html/section3_briefhist/Chronology.htm

[180] *Readings in the Philosophy of Science*, (eds. by) Feigl H. and Brodbeck M., Appleton-Century-Crofts, New York.

in the same year diffusing the habit of the application of behavioral experiments on animals towards the study of human psychology. This approach gave rise to behaviorism, one of the most diffused wave of thinking in psychology theorization and psychology research (for a main discussion and critics see section one).
In reason of its connection to our previous analyses we should remark that it is very interesting that Skinner starts the first chapter, named “The possibilities of a science of human behavior”, with a reflection about the “helping” power of science, compared to the discontent of World War II disasters (among all: atomic bomb).

> The story emphasizes the irresponsibility with which science and the products of science have been used. Man's power appears to have increased out of all proportion to his wisdom. He has never been in a better position to build a healthy, happy, and productive world; yet things have perhaps never seemed so black. Two exhausting world wars in a single half century have given no assurance of a lasting peace. Dreams of progress toward a higher civilization have been shattered by the spectacle of the murder of millions of innocent people. The worst may be still to come. Scientists may not set off a chain reaction to blow the world into eternity, but some of the more plausible prospects are scarcely less disconcerting. (Skinner, 1953, p. 4, [2008])

Coming from our prejudice on behaviorism dogmatic and elementariness approach one may get confused by the freshness of Skinner’s look, which seems to face some of the problems we are still handling nowadays about science responsibilities and science power in helping society (think about one of the main debates of years 2000 concerning OGM’s responsibility for hungriness solution).

> Torn from its position of prestige, science is decried as a dangerous toy in the hands of children who do not understand it. The conspicuous feature of any period is likely to be blamed for its troubles, and in the twentieth century science must play the scapegoat. (Ivi p. 4-5)

The phrase “science is decried as a dangerous toy in the hands of children who do not understand it” is quite expressive, nonetheless just few lines further Skinner resolves this frightening picture in the direction of the only “application” responsibility of science.

> Another solution is more appealing to the modern mind. It may not be science which is wrong but only its application. The methods of science have been enormously successful wherever they have been tried. (Ibidem)

The hypothesis of abandoning science is even compared to Samuel Butler’s *Erewhon* novel, “where the instruments and products of science were put into museums as vestiges of a stage in the evolution of human culture which did not survive”181. It is also very interesting to remark something about the title of the chapter “The possibilities of a science of human behavior”, because such as it is one may expect a transcendental analysis concerning the conditions of possibility of a science of human behavior *a’ la* Kant. While Skinner is talking very concretely, as an American pragmatic man of its epoch, coming out from two world wars and the atomic bomb. As he says in fact the responsibility of atomic bomb was clearly consigned in scientists’ hands and “since scientists are necessarily men of some intelligence, they might have been expected to be alert to these consequences” (Ibidem).
One may easily grasp from these excerpts that his concern is addressed mostly to one thing: solution. And the solution would consequently seem to come together with the suggestion of expressing a stronger control on sciences practices. Thus implying more responsibility. But here we should assert that this is not necessarily the case and that is why the term possibility in the title “The possibilities of a science of human behavior” is referred much more to its *practical* and concrete meaning, “help”, rather than the theoretical and Kantian one, “condition”. In a sense Skinner proposes a brilliant *logical* consequence of the *logical* premise about the terrific picture of the powers of science application that we may resume as it follows: science has a great power but has been applied with a lack of responsibility, or a lack of control, thus if we are able to find out a way to gain this control on science and scientists, thus on human in general, we have a solution. Then, “Let us apply science directly to human affairs, practices and cognition”.
I am sorry to keep adding remarks about Skinner’s reflections, but I am strongly convinced that many things would find their connection

---

[181] *Erewhon: or, Over the Range* is a novel by Samuel Butler, published anonymously in 1872, the name was conceived as an anagram of nowhere.

much more than one may attend. This is a key passage of our work in which we quest to understand the *Zeitgeist* of that epoch in which many different ideas, technologies and theoretical novelties first have developed, spread and fixed; creating some of the "tendencies" we still are dealing with; for instance: the central dogma of molecular biology, cell growth and cell proliferation description, cell cycle explanation and a performing cell theory and the same concept of interaction which entitles this work.
Looking for these connections and interactions some texts reveal revelatory power, and one of these is surely Skinner's book, where one may find the descent, "naissance" or the re-naissance of a lineage of "*topos*" in the history of thought.

> There is one difficulty, however. The application of science to human behavior is not so simple as it seems. Most of those who advocate it are *simply looking for* "*the facts*". To them science is little more than careful *observation*. They want to evaluate human behavior as it really is rather than as it appears to be through ignorance or prejudice, and then to make effective decisions and move on rapidly to a happier world. But the way in which science has been applied in other fields shows that something more is involved. Science is not concerned *just with* "*getting the facts*", after which one may act with greater wisdom in an unscientific fashion. Science supplies its own wisdom. (Ivi. p. 6, our italics).

I really do not know where to stop the quote and comment, as it shows the power of Skinner's rhetorical abilities together with his tenacious arguments, which may recall Brutus' words in Shakespeare's *Julius Caesar*. We have already seen the importance of the distinction between *facts*, *data* and *observation*, made by Husserl (Husserl, 1912), and pointed out also by Canguilhem with the expression "the monstrosity of the general fact" which here leads to a completely different interpretation. Skinner advocates a peculiar capacity of science that does not simply deals with facts, but that has its own wisdom.

> It leads to a *new conception of a subject matter*, a new way of thinking about that part of the world to which it has addressed itself. If we are to enjoy the advantages of science in the field of

> human affairs, we must be prepared to adopt the working model of behavior to which a science will inevitably lead. But very few of those who advocate the application of scientific method to current problems are willing to go that far. (Ibidem)

Here one appreciates the eulogy of the *renovating and overwhelming power* of science, that does not arise from *templa antiqua* rather it propose something strong and *new*, such as Skinner is personally proposing.

> Science is more than the mere description of events as they occur. It is an attempt to discover *order*, to show that certain events stand in *lawful relations* to other events. No practical technology can be based upon science until such relations have been discovered. But order is not only a possible end product; it is a *working assumption* which must be adopted at the very start. *We cannot apply the methods of science to a subject matter which is assumed to move about capriciously*. (Ibidem, our italics)

Finally appears the main actor of the crime: *order*. There should be an order to hold on, that justifies, proves and allows to correctly demonstrating one's ideas, in a sort of dogmatic research protocol, as we called it before. Here one may have the nostalgia of Galileo's description of mathematical order, though noticing that premises and consequences are in fact completely different. As we read in Gargani's book:

> Da un impianto metafisico-matematico prendeva le mosse anche Galilei; secondo lui il linguaggio e l'apparato categoriale della matematica definiscono contemporaneamente la duplicita' di funzioni di uno strumento che riflette la struttura profonda e reale del cosmo (al di la' delle apparenze ingannevoli e soggettive dei sensi) e che stabilisce la condizione metodologica di copertura e di legittimazione delle asserzioni scientifiche. "La filosofia e' scritta in questo grandissimo libro che continuamente ci sta aperto innanzi a gli occhi (io dico l'universo), ma non si puo' intendere se prima non s'impara a intender la lingua, e conoscer i caratteri ne'i quali e' scritto". (Galilei in Gargani, 2009, p. 36).

Gargani underlines that Galilei is the beginner of the great scientific-philosophical address that three centuries later was confirmed in Hilbert's thesis: *am Anfang ist das Zeichen,* in the beginning there is the sign (Hilbert, 1922). In Gargani's lecture with this orientation Galilei was transforming the problem of the conventionally corruptible and imperfect matter into a problem that was solvable only in terms of a linguistic-mathematical model (p. 39). In other words Galilei was changing the problem of a *physical* connection of objects and models into a grammatical one, more interestingly in this way he allowed to handle the problem barely in terms that were immanent to the grammatical apparatus of the object categories treated by geometry (p. 42). Skinner applies this same idea of order, connections and categories which are immanent and proper only to science's look and power of speech, but he is much more concerned in our opinion towards a practical scope: *control*. To put it better, also Galilei as every good mathematician and physicist was interested in control, in proving and testing his experiments, but he did not refer to what one may call a project of "human geometry", as behaviorism has been conceived.

> Science not only describes, it predicts. It deals not only with the past but with the future. Nor is prediction the last word: to the extent that relevant conditions can be altered, or otherwise controlled, the future can be controlled. If we are to use the methods of science in the field of human affairs, we must assume that behavior is lawful and determined. We must expect to discover that what a man does is the result of specifiable conditions and that once these conditions have been discovered, we can anticipate and to some extent determine his actions. Ibidem

Here we see in better light the confirmation or the re-confirmation of the mechanism of reification present also in much of the history of scientific concepts, such as the man-machine model that we have highlighted in chapter one and already commented together with Mecacci (1999) under the name of the "Universal Subject" question.

A thing that we find even ironic is that considering the anthropocentric factor or the maternal instinct that we have mentioned talking about scientists growth factor analysis, one may ask: why in the proposal of behaviorism is the man to be reduced to machine? Should we call it on the contrary a sort of "machine factor"? One paternal instinct that contrary to Titan's one makes prevail the kids (the machines) on their father (the scientist)? (Which kind of Oedipus' complex do we have here, *Herr Doctor*?). And along these lines it might not be such a coincidence that yet again in the same year 1953 Pope Pius XII, which established another *order* and another *dogmatic research protocols* with regards to those of science, in the article "The Technician", part of an extended series of publications on science matters, instructed scientists to restrict themselves to the study of physical matter and do nothing to undermine the idea of a "non-material soul or a Superior Being"[182].

We think then that all the concepts that we are underlying are to be found in the borders, which are the more permeable areas, of cell theory diffusion and reception. From this excursus it has been possible to better contextualizing S&S's strong critics of a "dogmatic research protocol" in cancer research as we called it, and in particular the SMT approach to cancer explanations.

Recalling our main proposal that the concept of interaction is built on a polarity between a mechanical-analytical approach vs a multifactorial-synthetic standpoint, we have seen this similar polarization in the recent history of the research on cancer and on cell proliferation. On one hand the SMT and the hypothesis of quiescence for the default state of cells proposed a mutation of one or plus genes (oncogenes) that would bring to dysfunctions in control of cell proliferation and to the development of neoplasia. On the other hand, S&S's (and others', see discussion above) proposal of proliferation as cells default state and a hierarchical level organization explains the origin of cancer without the employment of oncogenes and mutation but rather bases neoplasia's development on a flaw in the tissue-level organization. We easily recognize the two different approaches concerning interaction, the SMT being analytical, focusing on cellular level, and S&S's hypothesis being rather synthetic, because based on a global and hierarchical

182 "The Technician" was delivered as a papal address on October the 9th, 1953.

approach of the organism. Now we know that mutations, epigenetic and hierarchy of the cellular control are part of cell cycle that is related to cell transformation process, but this is a multifactorial mechanism that can act in multiple sites of the cyclic system. Therefore the critical points of damage can be multiple and specific for each type of cancer as a result of different changes in the machinery control of cell life. Recent evidences show a *double* perspective rather than a *polarized* one for the explanation of cancer development183. Probably this is the result of a more complex way of looking at phenomena, thus hinting that the synthetic approach nonetheless the strong mainstream opposition has been gaining step by step its explication power through years also in this field. This could suggest that also the main stream epistemological trend that we have tried to put in evidence in the analysis of the context of development of SMT theory (such as the central dogma hypothesis and the diffusion of computer science information model through behaviorism and beyond) might have been included in a more synthetic standpoint. As we know this is just again an "approximation" to a theory and the "cumulative" character of science (Oppenheimer, 1955) would probably bring again another opposition, and so on.

> I sistemi viventi sono enormemente diversificati durante l'evoluzione ed hanno adottato startegie di adattamento molto diverse. Non puo' quindi ragionevolmente esistere un'unica teoria dell'evoluzione che tenga conto contemporaneamente di tutte le facce della multiversita' biologica se non la si basa sull'accettazione del sincretismo reale della vita, che per restare tale ha inventato e sta inventando nuovi strumenti e nuovi processi di adattamento. E' d'altra parte comprensibile e tipicamente umano il desiderio di conoscere tutti gli oggetti sottoposti alla nostra osservazione e comprenderli in leggi "universali" che ci permettano di prevedere le dinamiche ed eventualmente modificarle a nostro favore. Buiatti (2008), p. 79.

[183] Partanen J.I., Nieminen A.I., Klefstrom J. (2009), "3D view to tumor suppression: Lkb1, polarity and the arrest of oncogenic c-Myc.", *Cell Cycle,* 1;8(5):716-24. Bianco C, Salomon DS. 2010, "Targeting the embryonic gene Cripto-1 in cancer and beyond", *Expert Opin Ther Pat.*, 20(12):1739-49. Frezza C., Pollard P.J., Gottlieb E. (2011), "Inborn and acquired metabolic defects in cancer", *J Mol Med.* Feb 8; Du C, Wang Y. J. (2011), "The immunoregulatory mechanisms of carcinoma for its survival and development", *Exp Clin Cancer Res.* Jan 21;30:12.

As Buiatti remarks, on one hand, in the beginning of the third millennium the various knowledges that we are accumulating are nonetheless pointing out that, in accord with the Darwinian sense of evolution, life sciences allow only a local elaboration of the “laws” and not, as we would desire, one and only theory of evolution that encompasses our whole history (in the three main characterizations of time: past, present and future). On the other hand, instead, by virtue of new and continuous amount of experimental researches, we can already try to find a more complex way of re-thinking those conceptual oppositions that have divided entire generations of scientists (mechanicism/vitalism, discrete/continuum, necessity/random, simple/complex, genotype/phenotype, body/mind, identity/plurality, fixity/evolution, independence/interaction…). The individuation and the discussion of the polarity of the concept of interaction might be a step in this direction.

Chapter three

The point of view of logic on the concept of interaction

I.

Le monde regorge de problèmes. Où que nous regardions, quelque problème nouveau surgit pour frapper nos yeux, dans notre vie personelle aussi bien que dans notre activité professionnelle ou dans nos affaires, au royaume des questions économiques tous comme dans le domaine technique, et dans les arts tout de meme que dans la science. Et certaines problèmes sont vraiment obsédants: ils se refusent rigoureusement à nous laisser en paix. La torture de notre esprit peut quelquefois atteindre un tel degré que nos pensées nous hantent à longueur de journée, et nous dérobent memme le sommeil de nos nuits. Et si par quelque hereuse chance nous réussissons à résoudre un tel problème, nous éprouvons un sentiment de délivrance et nous nous réjouissons d'avoir accru les richesses de notre savoir. Mais c'est tout autre histoire, et une impression aussi désagréable que possible, dedécouvrir après une longue durée de labeur et d'efforts, que le problème dont notre esprit a été la proie ne peut absolument recevoir aucune espèce de solution, soit parce qu'il n'existe aucune méthode certaine de le débrouiller, soit parce que, considéré à la froide lumière de la raison, il apparait comme absolument vide de sens: en d'autres termes parce que c'est un f*aux problème*, et qu'ainsi tout ce travail mental et cet effort ont été dépensés pour un pur néant. Il y a beaucoup de ces faux problèmes – à mon avis, singulièrement plus qu'on ne le soupçonnerait communément, - au royaume meme de la science. Planck, (1956), p. 101-102.

If you demand a rule from which it follows that there can't have been a miscalculation here, the answer is that we did not learn this through a rule, but by learning to calculate[184]. Wittgenstein

But remember: even when the calculation is something fixed for me, this is only a decision for a practical purpose[185]. Wittgenstein

First of all I have to make clear that linear logic does not have a specific aim of research that concerns biology. Neither my proposal is a concrete step in this direction. On the contrary, I am questing for learning something from a possible theoretical exchange between linear logic and biology, and in particular on the field of the concept of interaction, which is at the center of the interest both of biology and linear logic. One should remark then that this exchange is something I am personally trying to figure it out, thus, responding to my personal epistemological standpoint, this work does not want to go in the direction of any formalization. On the contrary it may suggest somebody else to proceed in this direction.

Modeling and simulating biological systems are both increasing fields of research the focus of which is translating into formal and/or virtual system some of the elements, such as properties or dynamics, of living systems[186]. The domain is vast and has its proper concerns

184 44. *Fordest du eine Regel, aus der hervorgeht, daß man sich hier nicht könne verrechnet haben, so ist die Antwort, daß wir dies nicht durch eine Regel gelernt haben, sondern dadurch, daß wir rechnen lernten*. Wittgenstein L. *On Certainty*, edited by G.E.M. Anscombe and G.H. von Wright, Blackwell Publishing, Oxford 1969.

185 49. *Aber bedenk: auch wenn mir die Rechnung feststeht, ist es nur eine Entscheidung zu einem praktischen Zweck*. Wittgenstein, cit.

186 Among all the different languages of biological systems modeling we

and specific questions[187].

My work undertakes a different approach, I am not looking for a machine programming language to build up a biological model; linear logic has not been developed to model biological systems. In spite of that I will consider linear logic's general approach and some of its specific techniques and ideas as possible instruments *per se* for a theoretic clarification and analysis of biological systems.

As we have already underlined, biology is strictly concerned with the topic of interaction, but why should logic bother about it? This is the first question we need to observe and analyze as an introductory key for our investigation. In fact, despite first impression, the idea is that interaction is a "locus" which has aroused an increasing interest also in linear logic.

The second aspect that I want to stress concerns the polarity of the concept of interaction. In previous sections (chapter one and two) I have tried to throw light on this aspect and to put in evidence the vicious circle it enhances. On one hand, in fact, we have seen that it is not strictly rigorous referring to interaction as a linear causal determination. On the other hand, we have noticed a tendency in the story of the term, and still in recent researches, that withstands in this employment. As we have discussed, it seems that

suggest to refer to Danos' works that have developed from a similar point of view of Linear Logic [Danos, 2001].

[187] For a very interesting analysis about developing virtual simulation of biological systems compare [Fox-Keller, 2003], in particular part three (Machines: Understanding Development with Computers, Recombinant DNA, and Molecular Imaging, pp.199-295) dedicated to a critic epistemological approach on the argument.

despite its fundamental meaning of “multifactorial”, “interference” and “feedback effects”, it is a common praxis to keep referring to interaction also as linear causation (one cause one effect and one effect one cause). A corollary to this question is: if physics’ and psychology’s researches highlight the polarity of the concept of interaction, why, then, another story of the concept has been handed down? (see the introduction).

A possible answer to this question that we are already able to hint, from what we have understood till now, is that the first idea of interaction (as linear causation) has allowed to *reduce* the problem of the entanglement of the complexity intrinsic in biological different levels of organization, even if not to *solve* it. While, on the contrary the second use of interaction, “multifactorial” (as the intrinsic deferment due to interference of measure instruments in quantum physics or the notion of disturb in biological analyses) does not allow to *reduce* the problem, but maybe allows to better *comprehending* it.

Here we hope to find some suggestions coming from logic's researches which could help us in better delineating this question also from a logical point of view. Our aim is clarifying this subject analyzing some possible *logic underpinnings* of the interpretation and of the use of the concept of interaction assumed from the two opposite tendencies (analytical and synthetic).

II.

Let us start with the first of the two meanings of the concept of interaction: linear determination. What is a linear determination? We have already hinted that linear *causation* is one cause that produces one effect and one effect that depends from one cause. This answer then implicitly includes the next: which is the difference between the notion of determination and that of cause?[188] Are they identical, or rather equivalent or isomorphs?[189] And this same question includes another one: how many meanings of "determination" exist? The answer to these question might have something in common to what we have already discussed in the first chapter about the distinction between interaction and force in physics. In that occasion, for instance, we have noticed that "interaction" and "force" are seldom used as synonyms. More specifically, when we talk about "fundamental interactions" we mean interactions that are the simplest ones and "all the known forces of nature can be traced to them". But we have underlined that more recently the traditional concept of force has been rather substituted with that of interaction (Oppenheimer, 1956, cit.).

[188] Anscombe (1975), *Causality and Determination*. In E. Sosa (ed.) *Causation and Conditionals*, Oxford, Oxf. Univ. Press.

[189] We refer here to the title of the 2009 LIGC Conference "Identité, egalité, isomorphism", Florence, Villa Finaly, 17-20 September, 2009.

Going further in this argument, referring to Wittgenstein I may add that:

> A meaning of a word is a kind of employment of it. For it is what we learn when the word is incorporated into our language (1969, n°61)[190].

And as we have put into light in the introduction the concept of interaction seems to have been highly incorporated into our language both in terms of frequency and in terms of diffusion through various disciplines. Then our research lead to the consideration of the different meanings corresponding to the distinct disciplines that have employed it (in particular physics, pshychology and biology). Then we are considering more in detail the first concept of interaction that we have underlined which is linear determination.

As first step to distinguish the different employments of determination, then, we can start from the different areas in which the notion is used, such as physics, philosophy, psychology, logic, medicine, law[191]. And we would find that depending on the subject, the object of the determination changes a bit. For instance, in physics when we say that something causally determines something else we mostly refer to the fact that we may predict the result of this interaction-relationship, as we will see in details in Planck's considerations. But in psychology when we talk

---

[190] 61. ... *Eine Bedeutung eines Wortes ist eine Art seiner Verwedung Denn sie ist das, was wir erlernen, wenn das Wort zuerst unserer Sprache einverleibt wird.*

[191] For a specific exam of the cause in the juridical field, which distinguishes clearly another area of the determination of the notion of cause see Nueburger, La prova scientifica nel processo penale, Luisella De Cataldo, Wolters Kluwer Italia, 2008.

about causality, for instance the occurrence of a specific brain pattern that instantiates a specific motor response, we mean not only that we may predict that the two events are happening in a specific connection, but also that they are alike, *i.e.* that one "is" the other. In fact we are not able to talk about one motor response or of a mental state from a *causal point of view* without relating it to the brain configuration and vice versa. As we have seen the debate about mental states is a strenuous argument that endure the minds of the philosophers[192]. We have here for instance a description made by Searle:

> Mental states on this view can be defined in terms of their causal relations to input stimuli, to other mental states, and to external behaviour. This view is called 'functionalism' and it is a natural development from token–token identity theory. However, the functionalist has to answer a further obvious question: 'What is it about the states that gives them the causal relations that they do have?' If mental states are defined in terms of their causal relations, then what is it about the structure of different neurophysiological configurations that can give them the same causal relations? (Searle, 2003, p. 13.)

The question that Searle poses about the contingency of a "causal" relation between a state and a mental state is interesting and implies a need of *widening* the notion of cause when treating mental activities, due to plasticity and redundancy of the brain activity. In fact there are many different brain configurations which may instantiate a same mental state and conversely there are same pattern in the

[192] For the problem of the existence of external facts and their relation with causing mental events see Malcolm (1984): Consciousness and Causality. In D. Armstrong and N. Malcolm, Consciousness and Causality: A Debate on the Nature of Mind. Oxford: Blackwell.

brain's areas which could instantiate different mental states (see chapter two).

We think that it is interesting to mention, and remember for our later discussion, this quote from Searle that adds some elements to the analysis that we have already done.

> There is a very natural way of connecting the computer functionalist conception of the mind with the causal theory of reference. If the mind were a computer program, and if meaning were a matter of causal connections to the world, then the way the mind acquires meanings is for the system that implements the computer program to be involved in causal interactions with the world. (p. 15).

Searle thinks that it is a very "natural" correspondence that which connects a "computer functionalist conception of the mind with the causal theory of reference". Even if the relationship with linguistic and the theory of reference is not properly in question in this work, I want to underline this proposal made by Searle because it seems very relevant for my analysis of the concept of interaction. In fact, the linear determination of the concept of interaction to which I have made reference (analytical perspective and the input-output model for behavior) is precisely taken into account by the computer-functionalist conception. It is interesting then that according to Searle's interpretation it is very natural to refer to the computer-functionalist approach and thus to a *causal* linear determination in explaining the constitution of meaning and reference. In other words, here again we see the consequences of a conception of interaction as a *determination* and moreover which is monocausal, linear and direct.

Coming back at the notion of determination we have discussed that in biology this notion is again something different as traditionally from a theoretical standpoint the idea of causality was related to that of law. In particular there are many scientists and epistemology researchers that sustain that *biological laws* in strict sense do not exist, with the exclusion of Darwin's evolution theory (see Rosenberg, 1999). In the field of biology the main criterion of physics that we have put in evidence which says that causality is something connected with prediction does not work at all. We have already touched this argument when treating biological versus physical conceptual oppositions in chapter two. We can see another point of view on this argument in a quote from Sober (2003):

> If the evolutionary regularity 'If P then Q' holds true between times t1 and t2 only because contingent evolutionary events E happened to take place at time t0, then it makes sense to say that the regularity is contingent. However, this leaves it open that the more complex conditional 'if E occurs, then (if P then Q) will be true later' holds true non-contingently (Sober 1997a). This point does not establish that biological laws exist, but it does show that one cannot establish that there are no laws just by pointing out that regularities depend on earlier contingencies. Furthermore, if causality entails the existence of laws (a metaphysical claim that should not be accepted uncritically; Anscombe (1975), for example, denies it), then the causal dependency of 'If P then Q' on E entails the existence of a law. Sober (2003), p. 329.

In this issue for instance we see that is claimed the idea of regularity and contingency rather than law and universality. As we mentioned (chapter two) in fact the more relevant trait of biological evolution is evolvability. In the lines of Evo-Devo theories, both phylogenesis and ontogenesis are forms of differently canalized variability. In fact, the core question of evolutionary developmental biology is evolvability, that explains how variation is generated through evolution and takes into account the pluralistic feature of organisms' developmental causes. More specifically, then in biology rather than the notion of law it is relevant that of constraint (Gould, Lewontin, 1979). And again this notion is related to the discussion about the notions of cause and teleology. The debate is immense (Sober, 2003), but what interests us here is to underline the specificity of the notion of cause and of determination in biology from a logical point of view. We can underline two cases: a correlation between the notion of law and that of cause and that between function and cause.

> It is important to distinguish the reason a trait evolved from the beneficial effects the trait has once it is present. But it also is important to analyze the workings of the current organism. Which account captures the real meaning of the word 'function' may be less important than the fact that both are, broadly speaking, causal accounts. Wright focuses on phylogeny, whereas Cummins focuses on ontogeny. Again, we must realize that 'function' is not a theoretical term used in biology, but is an informal concept that is used to talk about biological issues. Clarity is important if we are to avoid miscommunication, but clarity does not always require univocity. (Sober, 2003, ibidem)

In the biological relation between function and cause Sober puts in evidence how biology processes (phylogeny and ontogeny) concerns the development of functions which cannot necessarily described in terms of univocity of causes. I claim that what Sober says here about the non-univocity of biological principle deeply mirrors my analysis of the polarity of the notion of interaction. In fact at some level it is possible and useful to talk about "causality", "law" or "teleology" especially as forms of clarification and reductive descriptions (linear interaction), but at the same time one should remember the other side of the coin with the notions of "interference", "variability", "constrains", "cycle", "contingency" (multi factorial interaction). In other words the two sides of the coin are both at work in explanations, but while one side it is useful to make clear and remember that to some extent there is a "causality" even if we are not able to describe it apart from very reductive models, the other side of the coin stays into the complexity and tries to express this same difficulty by means of a non reductionist approach. In fact either one of the two approaches we dismiss we would probably fall into the temptation of metaphysical assumption: on one hand with the deterministic approach, for instance, sustaining the central dogma hypothesis of linear determination between genes and proteins, and on the other hand, assuming the holistic approach, one could feel free to propose dualism of the spirit and the body.

In conclusion I should resume that starting from different subjects we have also different meanings. These meanings in their turn influence again the ordinary meaning and the diffusion of the term, so both the scientific meaning and the ordinary one, in an evolutional circle of meanings[193]. In a very simple but direct and recapitulating phrase Wittgenstein (1969) says that:

> When language-games change, then there is a change in concepts, and with the concepts the meanings of words change[194].

Here we see what Woodward (2003, *Making things happen*) writes about the notion of causation underlining its multiplicity and plasticity:

> The theory (of causation) should be descriptively adequate in the sense that it captures relevant features of paradigmatic explanations in science and ordinary life. [...] If the theory recognizes different varieties or sorts of causal explanations (as the theory I propose does), it should show us what these have in common: why it is that they all count as species of the genus "causal explanation". Cit. in Gano (2008).

Evidently it is not possible and neither interesting for our aim to sum up here a "philosophical treatise" on causalit[195]y. This argument, in fact, for its prevalence, relevancy and incidence in the history of philosophy and science may even be considered the question of epistemology, which becomes inevitably a non-possible argument to be looked upon here. There are in fact many different scenarios that handle causality as a main topic

[193] For a magnificent work on meanings and their evolution see Emile Benveniste, *Le vocabulaire des institutions indo-européennes*, Tome I, II, 1966-1974, Les éd. de Minuit, Paris.

[194] 65. Wenn sich die Sprachspiele ändern, ändern sich die Begriffe, und mit den Begriffen die Bedeutungen der Worter. Cit.

[195] See Perret, 2011 for an historical excursus and for a specific analysis from an epistemological point of view on causality in biology.

also in philosophy: ontology, gnoseology, epistemology, and inside those for instance the metaphysical, or the theological perspectives or the teleological one. Trying to give the main intuition, the question of causality is so powerful because talking about the "cause" of something, it possibly brings into the scenario the question of the "why" of that something[196], which according to Kant's analysis is a typical question subject to the tendency of the Reason to enlarge its reasoning over its allowed limits and sooner or later may lead to the metaphysical question that sounds like: "why is there something instead of nothing?"; a question that "once in a while" has occurred in theological and/or metaphysical considerations…[197]. My question is much more modest, limited and specific, so for other kinds of argumentation one may refer directly to authorities on the subject and to their commentaries[198]. But for the purpose of introducing some very interesting conceptions and elements inherent to my discussion I should quote some references on the matter.

---

[196] See the difference in the "why" questions and the "how" questions, about which science should bother (Mayer, 1999) see also (Girard 2009) on this argument that explains from his point of view with a very clear example the distinction between an answer to the question why and the question how: "La France continentale est connexe *parce qu*'on peut lier n'importe quelle ville à Paris; mais ne pas mépriser la question '*comment* la France est-elle connexe ?' requiert de construire un réseau de communication beaucoup moins trivial qu'une simple étoile centrée sur Paris". Note 1, p. 1.

[197] See for instance an interesting review in Medieval philosophy, p. 625 Blackwell Companion. The question "why is there something instead of nothing?" is, for instance, according to Heidegger the core of the occidental philosophy, or the occidental philosophy in a question (Heidegger, 1929, What is metaphysics?).

[198] Traditionally, Aristotle, Descartes, Spinoza, Hume, Kant, Wittgenstein; for current debate, Wesley C. Salomon, Causality and Explanation, Oxf. Univ. Press, 1998; Woodward J. Making things happen, Oxf. Univ. Press, 2003).

III.

In chapter two talking about interactions, we referred especially to the cause-effect relation in the material biological world so it was impossible to avoid the reference to some extent to a physical-material determination. According to a physical point of view one can put in evidence at the same time the strong differences and the analogies with the logical use, which will be discussed straight afterwards.

The concept of causality in physics according to Max Planck is defined starting from establishing that everything depends from a clear comprehension of the meaning in which the world causality is used in physics.

> Bien entendu, on tombe d'accord a priori sur le fait que si l'on fait une référence à la "relation cusale" entre deux événements ou circostances qui se succèdent, ce terme est entendu pour désigner un certain enchainement régulier entre eux, en appelant le premier la *cause* et le dernier l'*effet*. Mais la question est celle-ci: Qu'est-ce donc qui constitue ce typer particulier d'enchainement? Existe-t-il quelque signe infaillible pour indiquer qu'un certain événement dans la nature est causalement déterminé par un autre? Planck (1956) p. 163.[199]

In Planck's belief the surest way to answer to that question is enlightening the link between the notion of cause and that of *the possibility of making accurate previsions*.

[199] (Planck, 1956) *Wissentschaftliche Selbstbiographie*, Bart, Lipsia. tr.it. *Autobiografia scientifica e ultimi saggi*, Einaudi, Torino, p. 74.

> C'est pourquoi je prenderai pour point de départ de toutes le considérations qui vont suivre cette simple proprosition, d'ailleurs applicable en dehors meme de la physique: *un événement est causalement détéeminé s'il peut etre prédit avec certitude*. (ivi, p. 164)

He underlines that this link does not mean that the two concepts are synonyms, but just that the possibility of an accurate prediction of the future is an "infallible criterion" of the presence of a causal relationship.

> Qu'il me suffise de mentionner seulement ici l'exemple bien connu que nous pouvons prédire avec certitude la venue de la nuit pendant qu'il fait encore jour, sans qu'il en résulte aucunement pour autant que le jour soit la cause de la nuit. (ivi, p. 164-5).

What is even more interesting is what follows this reasoning. In fact we cannot keep together the fallibility of the experience and the measure problem which is embraced in the principle "it is never possible to predict a physical phenomenon with absolute precision" (see chapter one) with the sentence above: a phenomenon is causally determined if it can be predicted with certainty.

Then, Planck explains us that scientists have chosen either to subsume that a strict regularity does not exist at all or that they have slightly changed the idea of *what is* a phenomenon: so in physical theory a phenomenon can stand also for something *purely theoretical*. In this way, scientists substitute the world of senses and that of measure with a world, which is the "image of the physical world" and which is a conceptual structure: created to allow scientists a precise correlation among concepts and calculus. Standing to Plato's metaphor of the cavern, we let go our mundane chains when we contemplate the mighty light of the sun and the idea of the good[200].

> Par conséquent, toute grandeur physique mesurable, toute longueur, chaque intervalle de temps, toute masse, toute charge, *a une double signification*, selon que nous les considérons comme directement donées par quelque opération de mesure, ou que nous les concevons comme transposés dans la représentation du monde elaboré par la physique. (Ivi.p. 169).

For the moment I particularly want to underline this element: the possibility of a dual meaning of physical objects, one which is "real" and one which is "imagined". But is even more interesting what follows: "it is absolutely false that the image of the physical world contains only directly observable objects" (Ibidem). Planck explains that the image includes "only symbols"; elements that have either a meaning very indirect for the phenomenical world or that do not even have a meaning for our normal experience.

> De tels constituants jouent d'abord le role de poids mort ou de ballast, mais ils seront pris en compte en raison de l'avantage dècisif qu'assure l'introduction du tableau scientifique du monde, - qui consiste précisément à nous permettre d'établir un rigoureux déterminisme (ivi, p. 170).

We should remark in this last passage by Planck the fact that here he is no more talking about causality, but of a *strict determinism* (*eines strengen Determinismus*).

Summing up we may notice that: 1) Physical objects have a

[200] See Malcolm, 1932;Ross, 1951.

dual meaning; 2) These two meanings are opposed as one preserves strict determination, while the other contravenes it; but contrarily to our expectations founded in tradition, the one that contravenes rigorous determination is that of reality rather than the imagined one! 3) There is a tendency in science's practice of questing for a closure of the causality of the world, so that:

> Tandis que dans le monde des sens la prédiction d'un événement comporte toujours un certain élément d'incertitude, dans le tableau du monde dressé par la physique, tous les événements se succèdent en accord avec les lois rigoureuses et définies, - ils sont déterminés apr une stricte causalité. (p. 172).

For my purpose it is very important to remark that physics underlines a dual meaning or determination of causality, one especially created as taking into account a world were "everything" could be summed up well! We can correlate this fact with the analysis of the notion of interaction, and precisely with the two opposite determinations of interaction that we have enlightened. Keeping the metaphor above, it is important to underline that from a strict linear-causal determination, biological phenomena do not sum up at all! As we have underlined biological systems rather show complexity, emergent properties, variability, examples show counterexamples and theories counter-theories[201]. All the cases of biological phenomena that we have analyzed in chapter two focus on variety, dualities, opposition, influences, resistance, instability, evolution,

[201] See also the ago-antagonist processes described by Bernard-Weil, 2000.

extinction, in a world: they are not *images* of the world, rather they make the history of the world through evolution, and they have themselves a history and their evolution[202]. After having established that living systems are not images of the world but part of it the question that arises is whether they could be better comprehended creating a totally abstract and imagined world especially made to describe them, such as physics has done, rather than trying to sum in a unique theory all living complexity present in the real world.

Talking in the terms of the concept of interaction we should say that in iving beings' dynamics, life and evolution the interaction is intrinsic, thus gives an "interaction-twist" to every analysis: an entanglement which only from a theoretical point of view is distinguishable in different levels of explanation. In phenomenological terms one may stress an eidetic point of view to look at phenomena thus knowing that is is just a perspective and contemporary that we cannot see but as if always "in perspective" through it. In the words of *GT's* analysis *we discriminate* in our perception of the experience. We may add with Berthoz and Petit and Husserl's description of *Abschattung* and of the eidetic dimension that vision and an experience are always in perspective, nonetheless directed by means of intentionality with a twist of virtuality, by means of all the

[202] Thing, this, that an image very difficultly has; except the wonderful work of *Pathosformel* and *Bilderatlas Mnemosyne* by Aby Warburg, where images live their life, but it is quite simple to convene that those images are completely different from the image of the physical world, Warburg, *Mnemosyne. L'atlante delle immagini*, Aragno, Genova, 2002 (Conferenza alla Biblioteca Hertziana di Roma, 1929).

other intrinsic perspectives implicated in the actual one (see chapter two). And at the same time this process is co-constituted in a non direct personal standpoint but rather in intersubjectivity. In other words, even when referring to our center, to our point of view that of the Ego we are not in the center of it, but always deferred. Our constitutive interaction is a continuous interference and a clinamen from our linear determination both directly in life and from a theoretical point of view when discussing living beings. This fact could suggest us to defer even more the plan of the analysis and push it in a complete fictional dimension as quantum physics has done.

IV.

What do logic says about causality? In the script *Project* (2009) which is one of Girard's most philosophical scripts, thus quite impossible to be understood but very adapt for my discussion, Girard considers three main logic circles that are three general ways of considering from an historical and from a methodological-philosophical standpoint logic's developments. We have to put into light that here for the sake of the discussion we could not enter into the technical details, which by the way are also one of the main distinctive traits of linear logic. Nonetheless, as I have put in evidence in the beginning of this chapter my analysis is undertaken only from an epistemological point of view which is also the only one I am practically able to offer. In other words all references to precise technical-experimental questions should be rather discussed directly into the original texts.

> Le problème de fond de la logique est de comprendre ce qu'est une démonstration de A. Pour cela on cherche un partenaire qui réfère toujours à la négation de A et on construit une dualité (exprimée sous forme de complétude). Le cas classique, c'est la dualité démonstrations/modèles : A est démontrable quand sa négation ¬A n'a pas de modèle. Elle relie les démonstrations de A et les modèles de ¬A dans une dualité frustrante où les deux partenaires s'excluent mutuellement. On comprend tout de suite que cette position sera difficile et aussi que la dualité est reliée à la négation. (Girard, 2009, p. 1).

Girard distinguishes four main logics by means of their relation with dualism. The first circle is classical Hilbert reductionism. The duality here is flagrant, demonstrations (finite objects) are model ("observations") of the world (infinite models). It appears a relation between the finite and the infinite dimension. Hilbert, remarks Girard, proposed a conception of the infinite as ideal limit of the finite processes, thus implying the approximation in the results. As well pointed out this kind of re-comprehending the infinite within the finite, is not a limit of our approximation methods, but rather it is a result of Gödel's theorem (1931) by which the process of prove includes an irreducible infinite[203].

Girard underlines an analogy with the continuum and the unstable behavior of differential equations in physics, which recalls the topic that we have mentioned in the first chapter about the principle of indetermination: the impossibility of giving a finite, or complete, or exhaustive, or linear determination to physical phenomena in reason of their friction with measure instruments. This Hilbert's duality is also to be intended as the duality between the observer and the world to which we have made reference many times in this work (chapter one and two).

From what is in evidence here, even if not explicit in Girard words, we may hint that the explanation that Girard calls “Hilbert reductionism” does not grant a dynamical or multifactorial logic idea of determination; on the contrary we rather see a reflex or an analogy with the physical linear one that we have mentioned above (one cause one effect and vice versa, and the hypothesis of predictability).

The second circle is the “Gödelian uneasiness” (“malaise”) which is the evolution of the first circle. Here the duality becomes even more clearly expressed in terms of demonstrations and models, and as a matter of fact this cercle encompasses the largest part of the world of logic such as model theory. Also in this case the infinite cannot be avoided, but in a different way. Here Girard using the

[203] Gödel (1931), for a well-detailed analysis of the theorem see also the introduction of Girard in Le champ du signe. In Le théorème de Gödel, p. 141–171, Paris, 1989. Le Seuil. And the Italian edition Il sogno del segno in La prova di Godel, Boringhieri 1992, see also chapter 2 of Girard Le point aveugle (2006).

metaphor of chemistry propose that the observer is reduced to a physico-chemical dimension or as in classical logic the proofs can be coded (Gödelization) but do not have a peculiar dimension. Moreover in 1934 Gentzen's *Haupsatztheorem* allowed to rewrite the proofs, getting rid of the notion of infinite in the theorems by means of finite calculus (" le calcul des séquents qui étayait une élimination de l'infini dans le style de Hilbert... en contradiction avec l'esprit du théorème de Gö del...". (Ivi, p. 1)). But the application of this calculus to Peano's arithmetic made by Gentzen later (1936) requested even more infinite techniques. That is why this is a "hybrid creation", as Girard defines it, which was not easily accepted within the very limited dualistic frame of demonstrations and models.

For the moment we can comprehend that this second circle, even if technically has tried to overcome the dualistic opposition of infinite and finite and to give a different account of linear determination, nonetheless had not been able to establish another functional idea of logic determination. Intuitively, from what we have already put into light we may hint that we are not searching for a *hybrid* solution, but for one that takes into account a polarity solution: one that accomplishes and keeps together in a connection linear determination with a synthetic one.

And going further, the third circle is Brouwer's intuitionism. Let us start with Girard's remark that Brouwer has provoked a breakup with duality. In fact, recalling the distinction above, despite the first circle where the duality is in the opposition between a world and an observer and between finite and infinite, in Brouwer's approach the external world "does not exist" at all, because proofs refer directly to themselves (and not to their model), in a sort of monism-subjectivism. And we should add another characteristic that Girard frequently underlines: subjectivity is very different from subjectivism[204]. In the terms of the opposition between infinite and finite Brouwer proposes an "anti-logic interpretation of the infinite" (Girard, 2006). Brouwer does not refuse the infinite (contrarily to Hilbert), in spite of this he rejects some of its "actual" aspects such as set theory and the idea that the real variable function may be defined point for point. This reversed standpoint on infinite explains why in intuitionism some principles that are valid in the finite domain are no more valid in the infinite one such as the principle of "*tertium non datur*" (A or non A). And we should add that also one of the main principles of duality, which is the negative involution, is forbidden in intuitionism.

As we may have already remarked linear logic puts a peculiar attention on duality and for this reason underlining the importance of the duality principle of the negative involution Girard even defines linear logic "a symmetric version of the intuitionism" (2006, p. 8).

The exclusion that one finds in intuitionism of some of the

[204] For instance in its talk about Negation in LIGC 2008 where the distinction between subjective and subjectivism was at the core of the idea of the group LIGC (Comment to Lestel's talk). See also Girard...

important principles admitted in the infinite domain has been later changed by a hybrid solution. The interaction between proofs à la Brouwer and Gentzen's technique has showed the importance of another rupture in logic: typed lambda calculus has put in light peculiar mathematical underpinning, the closed Cartesian categories[205].

In this cercle with intuitionism we are confined in subjectivism realm, but Girard gives another characterization to it which is very interesting. Rather than considering intuitionism as this closure on the subjective it could be more relevant to make a parallel with the relativity theory's way of thinking the time as the quantification of the motion made by an observer. Thus we see: the duality between objects and their models and between the *observer* and the world is broken and the *subject* is now itself producing his constructions. In this standpoint we should remark that polarity and plurality nonetheless does not seem to find a well-established status. While from what we have already discussed we need to put into light the importance of polarity for considering interactions and consequently a world that includes plurality. A world in which dominates one and only subjectivity is also a world where this subjectivity, seldom the Universal Subject, is the one that poses the questions and the same one that answers to them (chapter one and two). In particular for a description of dynamics and errors, which are the basis of a living beings' world, I have enlightened the importance of a

[205] See Girard (2006).

plural, based on interaction and historical way of thinking living beings' processes, organization and behaviors (chapter one, in particular Vygotsky).

There is another traditional point of view concerning the main distinctions between different circles of logics, which is made in terms of the distinction between syntactic and semantic.

> En suivant ce fil directeur, il est désormais facile de relire l’opposition entre classiques et intuitionnistes en termes sémantiques. La logique classique portait essentiellement sur la transmission de valeurs de vérité, et exigeait comme condition de possibilité d’une théorie de la démonstration que la vérité soit conservée dans toutes les opérations logiques possibles. Un tel système n’est pas très difficile à obtenir, les logicistes, et Tarski en particulier, ont bien formalisé cette exigence en promouvant un cadre déterministe et calculatoire à une telle logique des valeurs. (Tronçon, 2006).

In fact traditionally it was distinguished between syntax (language and description) and semantic (object and model). In this scheme we may easily recognize the illustration in circles we have mentioned above. In fact we notice again an evident dualism between on one hand the descriptions and on the other the world. The distinction of syntax and semantic is connected also to the method of proofreading and to the question of completeness. The main principles of demonstration in fact become respectively: “what is demonstrable is true” and “what is true is demonstrable”.

This brings us to what Tronçon (2006) said above about Tarskian “logic of values”, or in other words, of a logic the focus of which is preserving trueness among all logical operations in proofreading. This idea was conceived by Tarski in particular by means of the introduction of a meta reference for the trueness of the proposition. For instance having the demonstration of A, the trueness of A is A, but which refers to a meta-A. In other words, this means that the arithmetic trueness is not definable inside arithmetic, but it is "*hyperarithmetic*" (Girard, 2006, p. 40).

Going back to the circles' scheme, the fourth circle described by Girard is the "Geometry of interaction" or GdI which has reintroduced a dual perspective in logic's explanation by means of a subjective monism (which in fact is not subjectivism), in which monism stands for the fact that the objects that are considered are all very much alike (similar nature) and are not dualistic (objects/models or world/observation). There are many different ways to describe GdI, but a clear one is that it has been created from a conceptual antithesis. Traditionally, when manipulating the syntax (formulas, proofs, ...) via rewriting procedures, one obtains just a formal dynamics, as we have seen (Girard, 2009, p. 1). On the contrary, in GdI the dynamics pre-exists and the syntax (formulas, proof, ...) becomes only a "commentary", a label, of the "quasi-physical objects" which have their proper dynamics, and not the *motor* of their dynamics. Now we see that by means of this approach we are in presence of objects, so surely not in the subjectivism, but at the same time we lose the subjective point of view. Or in other words, from what said, we see that we are out of both dualities of the first two circles (world/demonstrations and demonstration/models), but we are not already able to see in which duality we are. Another way of clarifying this “non-subjectivisme” or “duality-monism” point of view, as Girard calls it, is that GdI has arrived to conceptualize the notions of program and execution of the program, in a theoretical frame that is non-anthropomorphic, *i.e.* without the point of view of a subject that waits the machine to produce a result, such as in the Turing machine case (Turing, 1937)[206]. In other terms:

> Il s’agit ni plus ni moins que d’expulser totalement la syntaxe de la description des démonstrations pour les remplacer par des opérateurs. (Girard, 2009, p. 22).

As we can easily understand, a fine analysis of GdI requires a very specific method and proper mathematical and algebraic underpinnings which we are not able to propose[207]. It is relevant to remark also that it might be easier to offer a different point of view on the subject when one is not concerned by the internal dynamics, sometimes disputes, of a discipline. Also because as consequence of what we have already remarked concerning a polarity principle at work in every possible way of thinking (William James' metaphor, chapter one), “the activity” and “the description of the activity” are seldom in a mutual

[206] See also, Girard, “La logique au milieu du gué : logique naturelle et intelligence artificielle”, in *La machine de Turing*, Paris, 1995, Le Seuil.

[207] Towards a geometry of interaction. In Categories in Computer Science and Logic, pages 69–108, Providence, 1989. AMS. Proceedings of Symposia in Pure Mathematics n◦92.

exclusive correspondence. One should focus then either on one or the other.

> La relazione esclusiva tra la pratica di un'arte e la descrizione di questa pratica. Ambedue fanno parte di una vita civile. Ma un'analisi delle cose che si fanno e di questo fare le cose è difficile da condurre completamente. Oppenheimer (1947), 1965, p. 44.

Keeping in mind our purpose, which is trying to illuminate some possible ways of dialogue between logical and biological consideration on interaction, we may put into light just some main aspects of GdI.

V.

The first element I want to stress is that GdI does not *describe* "existing physical interactions", as in the idea of a syntax that describe a semantic, because GdI comes out from a physical reference itself, "mon intuition méthodologique est physique" (Ivi, p. 2). Girard uses the analogy with physics mechanics that is based on a fictional (imagined) finite system for which a certain number of invariants are null (see Planck's description above). In order to study a system S one adds the "rest of the world" R, gaining a close system $S+R$ and it is exactly this passage of the "rest of the world" in the second member that allows writing the equations for S. In other words one may enlighten some complementarities or dual points of view at work in GdI logic procedure. In fact, the linear negation of the proof A has the role of the physical *R* "rest of the world" for the proof A.

An important commentary of this is that in terms of completeness à la Gödel this approach refers always to an i*ntern criterion of completeness,* which as we will better comprehend goes together from its procedure standpoint.

> A propos de complétude, on est en train de découvrir que la complétude de la logique est purement interne, autrement dit qu'il y a des moyens d'exprimer le fait que rien n'a été oublié sans référer à un univers extérieur dans lequel la logique préexisterait. (Girard, 2009, p. 3).

Going back again to Tronçon's analysis of GdI that we have mentioned above, we may describe with his words the evolutionary changing operated by GdI:

> Alors que logique classique et logique intuitionniste peinaient à rendre compte avec toute la justice qu'il se doit de cette double nature formelle, entre la dynamique globale de constitution de l'univers des significations et la prise-en-compte de l'aspect interactif et géométrique des notions de règle et de démonstration, un nouveau point de vue apparut. Ancré profondément dans le procédural, ce dernier permettait de rendre compte, dans un meme formalisme, des déterminations statiques et dynamiques issues de la logique historique, et de la dimension holiste et interactive rendue incontournable par des considérations épistémologiques et cognitives. (Tronçon, 2006, p. 13)

A crucial point, as we have already mentioned is the "procedure standpoint" and the rupture with the traditional dualistic opposition between syntax and semantics. This rupture opens up to a more mature comprehension of the principles of symmetry, geometry and of the dynamics between the objects (proofs), in a word it introduces a specific interest on interaction!

As Tronçon underlines in the theoretical underpinnings of GdI what is amazing and innovative is taking into account directly both of the technical and theoretical aspect together. And we should add not in a synchronic meaning (in the sense that one does two things at the same time) which is not a novelty, as for instance also classical and intuitionist logic have created “a theory” together with a technique, but that the theoretical and the methodological (procedural) aspects are the *very same thing*, in a word: “dualistic-monism”. This approach again, as mentioned above, means the pre-existence of the procedure, the dynamics, with regards to every observation or commentary of it or of a syntax which describes it.

Another possible commentary is that this approach is tuned with what we have said in chapter two about Vygotsky's historic way of thinking of culture and behaviors. In fact it allows to carry on a complex, interactive and living idea of cognition, and more generally of human practices. Again, taking into account the importance of historical and evolutionary criteria, which is not very common in logic attitude, requires to break with a linear determination. This fracture may imply also to eliminate the idea that something is made forever; even a theory or a calculus is subject to modifications.

I want to precise that while the linear determination, or *static*, describes the state in which a specific system might be at a certain time of its evolution, the *dynamical* standpoint takes into account the disturbing phenomena of that very state, which may occur at any time. This approach, in other words, concerns processes and not sentences or proposition about processes and thus it is much more appropriate to consider living beings, as in biology there are only processes, dynamics or more properly "transitions".

Individuals, as we have mentioned several times, live in a peculiar "quivering state" always in a threshold of potentiality between development and evolution in a "punctual extension" of life. This means that although throughout the multiversity of the possibilities of action and the creative answers via biological variety of phylogenetic and ontogenetic co-possibilities, which are always not pre-definite trajectories, but evolutionary possibilities (contrarily to geodetics of physics, Bailly-Longo, 2010) the individual's life is a *hybrid*. It is extended, but in the meaning of a non-reversible extension: the evolution implies non-reversible changing and extinction. The individual lives in a threshold that is critically extended (Bailly, Longo, 2010) and in a time, which is *all spent* though in a double perspective. It has been described a specific temporal dimension of the individual, which has the clue of an iterating temporality similar also in a non-specie-specific reference (such as cardio and lung respiration, see Longo, Montevil, 2011) coexistent with the physical time, proper to all inert and living matter.

All this implies an historical and *consumed* time, even if from the phylogenesis point of view it may seem that the individual life is further extended in the phylogenesis chain. If we look at the process of evolution in its complex (thing that it is never possible in its complete dimension, as a whole) one may have the impression of a long and infinite “chain of life” (Lovelock’s *Gaia*, 1975) made by all the evolutions of individuals and species[208]. Nonetheless the most relevant characterization of life is historical, through time and is gained by means of “irreversible processes” both as extinctions and individual’s death; not to mention the importance of errors, the memory of errors and all dualities mentioned previously. Thus, again the analysis of biological processes requires specific conceptions and eventually non-deterministic ones.

This emphasis on dynamic, historicity, employment of resources and of time and on the distinction between reversible and non-reversible processes finds a possible logic counterpart in GdI's approach.

> Nous étudions alors des processus dans lesquels l’exécution ne dépend pas de la logistique des propositions mais d’un équilibre géométrique entre structures, et dans lesquels une nuance et faite entre données réutilisables *ab libitum*, et données restreintes à un usage unique. (Tronçon, 2006, p. 14).

[208] See for instance Ernst Haeckel's recapitulation theory, or biogenetic law, which was often expressed as "ontogeny recapitulates phylogeny", i.e. the development of an organism exactly mirrors the evolutionary development of the species.

VI.

Now we may pass to observe the first question that has brought us here: why should logic bother about interaction? In particular, as we mentioned, we are referring to a specific field of logic, which is linear logic. We may answer directly quoting Jean-Yves Girard, who is also its creator.

> Bien que mathématicien, j'ai la chance de travailler dans un domaine qui a toujours affiché, pour le meilleur comme pour le pire, des prétentions philosophiques. C'est seulement en 1987 que j'ai conçu un programme qui ne se résume pas à une liste d'exploits à accomplir. Ce programme de *Géométrie de l'Interaction* proposait une vue originale de l'activité logique, sur un fort arrière plan mathématique, celui de la théorie de la démonstration. Ce programme était aussi l'illustration d'un changement de point de vue avec l'abandon des obsessions fondamentalistes (le *pourquoi*) au profit d'une approche en apparence plus modeste (le *comment*) qui suscite la construction d'un appareillage mathématique beaucoup plus fin. (Girard, 2009, p. 1).

Trying to comprehend why interaction is important for linear logic means entering directly into the very procedure of it, as I have remarked. Linear logic, such as it has been conceived and illustrates by Girard many times ("Linear logic", *Theoretical Computer Science*, 50, p. 1–102, 1987; Girard, 2006), is not a portfolio of techniques and calculi of logic, but it tries to incarnate the procedure of the very calculus itself. It is a conception of logic that starts from the idea of procedure. The idea of procedure gives an “internal completeness” key to look at linear logic which is both intrinsic and synthetic.

There is also another standpoint to look at it, or better another kind of conceptualization that has been resumed in the introduction of Girard’s work in (2006) *Le point aveugle* and which is emphasized in fact in the same title: the blind spot.

As a possible purpose of the book, Girard suggests “la révélation d’un desordre dans cet univers apparemment bien rangé” (p. xiii). The intrinsic intention of the linguistic turn in the beginning of past century was the supposition that all matters were susceptible of a mathematization. In a sense this is the phantom of transparency: the idea that everything can be simplified, because it can be explained. While, on the contrary, after Gödel’s results on incompleteness, this perspective was profoundly made wavering, introducing as a response the “emergence of the meta-critics” (see Girard, 2006).

There is also another internal feature in the linguistic turn: a sort of relativistic attitude or de-realization.

> Un linguaggio è un alfabeto finito grazie al quale costruiamo dei termini, degli enunciati, delle dimostrazioni – la sintassi – . Il linguaggio è poi interpretato in un modello – la semantica – ; infine tutto questo è formalizzato in un meta-sistema. (Ivi, p. xv).

The blind spot is what we do not see and that we do not even know that we are not seeing.

> La bonne nouvelle de ce cours, c'est qu'il semble que le point de vue procedural soit à meme de débusquer le non-dit, le non-vu. (Ibidem)

The main hypothesis of Girard (2006) is the profound inadequacy of classical logic. In particular Girard sustains that classic truth is an essentialist illusion that is auto-determined, while the completeness theorem (1931) can be seen as the non-existence of the truth.

What linear logic does is a shift from the real feature of reality (the world) towards the unreal: the analysis of the more "real" structure of logic. Is this step that allows logic to look into its same eyes and seeing the abyss reflected into them, as Girard says recalling Nietzsche. Or in other words:

> Elle parvient ainsi à toucher ce point aveugle où l'essentialisme nous ment, ou du moins se refuse à toute justification autre que "c'est comme ça". (Ivi, p. 12).

The more natural development of the logical idea of interaction is Ludic. The term Ludic as Girard explains in (2009) comes from the need of replacing the term "Geometry of Interaction" and being the expression "monism duality" too obsolete and that of "dialectic" being too denoted, "nous avons opté pour cette expression sans prétention qui rappelle la nature interactive de l'approche". (Girard, 2009, note 2, p. 3).

VII.

We have often put in evidence the peculiar attention that Linear Logic gives to the concepts of duality and negation. Now we may even intend the ideas of duality and negation as the motor of the interactions and of the procedure standpoint, which we have mentioned above. In particular Linear logic has put in evidence the conceptions of duality and negation in a new perspective for logic and also from the point of view of methodology and reasoning in general.

> Le problème de fond de la logique est de comprendre ce qu'est une démonstration de A. Pour cela on cherche un partenaire qui réfère toujours à la négation de A et on construit une dualité (exprimée sous forme de complétude). Le cas classique, c'est la dualité démonstrations/modèles : A est démontrable quand sa négation ¬A n'a pas de modèle. Elle relie les démonstrations de A et les modèles de ¬A dans une dualité frustrante où les deux partenaires s'excluent mutuellement. On comprend tout de suite que cette position sera difficile et aussi que la dualité est reliée à la négation. (Girard, 2009, p. 1).

In fact, as we know, the model theory is inscribed in a dualistic conception in which the infinite side cannot be completely eliminated (a hybrid or finer version of the Hilbert reductionism).

But to understand the power of this idea and the novelty of duality-monistic approach and of negation we may look at how has been conceived linear logic. This is a direct description by Girard:

> A ce moment là (fin 1985), je me suis rendu compte que l'opération fondamentale du typage (la flèche $\sigma \to \tau$ entre deux

> types, qui est aussi l'implication intuitionniste) n'est pas primitive : elle se décompose en opérations plus simples. Il n'était pas évident a priori que cette décomposition pouvait être internalisée, c'est à dire exprimée au moyen de nouvelles opérations logiques; (Ibidem, p. 18-19)

This is why Girard refers to its work as a refinement of classical and intuitionist logics. In linear logic it is possible to rewrite all the logical operations by means of some non-trivial distinctions. For instance the intuitionist implication A □ B can be rewritten as (!A) $\multimap$ B, where A $\multimap$ B stands for the linear implication *that has the meaning of a causality*[209]. "!" means that you may use as many times as you want A, and corresponds algorithmically to a storage ("mise en mémoire").

What Girard explains is that from this point it has been possible a deeper discover: *linear negation* that from the procedure standpoint represents the exchange between entry and exit, thus A $\multimap$ B is *identical* to B□ $\multimap$ A□, that is the *analogue* of the transposition in linear algebraic.

For the moment I may just remark that here we have another definition of causality proper to linear logic that we can add to our investigations above: the *implication has a causal meaning*. And by means of the propriety of negation the exchange between entry and exit (or input and output) becomes possible thus they become *identical*. This better clarifies the question that I have proposed in the beginning of this chapter when I was trying to put in evidence the

[209] Algorithmiquement, $\sigma \multimap \tau$ est le type des algorithmes fonctionnels de σ vers τ qui appellent leur argument exactement une fois) ; Girard, 2009, p. 19

various possibilities of the concept of determination and the different nature of the relations such as equality, identity and isomorphism. Here we see that in linear logic the cause is implication and the power of the operation of negation is the involution, thus A −◦ B is identical to B□ −◦ A□.

> Du point de vue technique, la logique linéaire se présente comme une modification très naturelle de la logique usuelle, formulée à la Gentzen : on se contente de faire disparaitre les règles dites d'*affaiblissement* (de B déduire A −◦ B) et de *contraction* (de A déduire A □ A), qui énoncent précisément l'absence de problèmes de ressources ; (Girard, 2009, p. 18-19).

I may underline that adjective "natural" in the quote. In fact the meaning of the term "linear" of *linear logic* is used to preserve the idea of the notion of "natural" in natural deduction. Linear logic with its focus on procedure has discovered also the problem named of incarnation, or that of the employment of the resources. This means that a clear distinction with traditional logic is established by discovering many different connectors that means resources' dynamics. Girard explains that the term resource stands both for the calculus time and storage or "memory space" or in other terms it can be considered as an exchanging value such as money is (Girard, 2009, p. 19). This is an explanation of linear logic topic on exponentials.

> Par contre ces règles restent vraies dans le cas où A est de la forme !C, c'est à dire les deux règles deviennent les règles du connecteur "!". En fait toute la logique linéaire est batie sur une analogie avec l'algebre linéaire : "−◦" se comporte comme l'espace des applications linéaires, "□" comme le produit tensoriel, "&" comme la somme directe, "!" comme l'algèbre symétrique etc. (Ibidem, p. 19)

We can imagine why then another argument concerning the logical concept of interaction is put in evidence by means of “proof nets”. Again, the idea of proof net is based on procedure and linear logic methodology, thus should be explained as a connection of things and not as a description of objects that preexist the procedure or their interaction, or in other words: the existence of objects is not identical neither equal nor isomorphic to their essence! Then the interaction between proofs is direct and plays its role connecting the proofs mutually and offering the possibility of writing and rewriting again a same proof in another way, from another point of view. As I mentioned above this is due to the internal completeness of linear logic, which does not take into account a meta-world to understand or establish its proper world as it was in the case of the first circle hypothesis (Hilbert) described above.

We may comprehend then from another standpoint what I enlightened above about the power of duality and negation.

> Mais l’enjeu fondamental reste les fondements de l’algorithmique parallèle, et c’est là-dessus que j’ai fait porter l’essentiel de mes efforts, en partant de la remarque que la négation linéaire est involutive, comme celle de la logique classique, avec en plus un sens algorithmique (on sait que c’est faux en logique classique : voir les théorèmes de théorie des nombres qui énoncent l’existence d’entiers sans qu’il soit possible de les calculer). L’involutivité de la négation permet de postuler l’équivalence des entrées et des sorties, une entrée de type A pouvant etre vue comme une sortie de type A□ et réciproquement : on perd ainsi la notion (ou plutot la fiction) d’un calcul qui serait orienté de l’entrée vers la sortie, puisque, si l’on veut, il n’y a plus que des sorties, et on se retrouve dans un univers de calcul parallèle. Ce qui induit une “parallèlisation” de la syntaxe (Ivi, p. 21)

I should underline then two different facts. The first is the loss of the direction of the proof, or as we will see straight afterwards of the notion of *order* in a proof. This means also that proofs loose their classic linguistic character mentioned above which is an abstraction from the choice of the rules that have been used to form the proof. In a word this procedure emphasizes the intrinsic geometrical aspect of proofs. Evidently the traditional meaning for which a proof is a series or a tree of propositions (formulas) established by means of the rules of the calculus results completely changed.

> Le premier problème résolu [...] était de trouver une nouvelle syntaxe, plus proche du calcul que les formalismes à la Gentzen. Ces formalismes contiennent en effet des informations redondantes qu'on est ensuite obligé de gérer, de modifier : c'est typiquement l'ordre d'application des règles logiques, qui n'a souvent d'autre signification que la nécessité toute bureaucratique d'écrire des règles dans un certain ordre. Les réseaux de démonstration écrivent (pour le fragment logique mentionné plus haut) les démonstrations (ou les programmes) sans ordonner les règles, c'est à dire sous forme d'un graphe à conclusions multiples (Ivi, p. 21).

This is in fact the second element I want to put into light: linear logic proofs are *graphs* instead of traditional trees. A property this, which is allowed by the intrinsic geometry of proofs and by the loss of the order in proofreading. In this way one discovers the possibility of the parallel calculus of proofs and, thus by virtue of this natural connection they could be integrated in *proof nets*.

> Le problème mathématique qui se pose est alors de savoir reconnaitre, parmi tous les graphes qui se présentent, ceux dans lesquels on peut trouver au moins un ordre pour les règles, c'est à

dire ceux qui sont séquentialisables. La solution consiste à donner des instructions de voyage dans le réseau, dépendant du positionnement préalable d'interrupteurs;

Here Girard employs the electrical metaphor "the switch" which is one of the clearest to understand how proofs are sequenced or how they mutually communicate together. Again we see that in linear logic everything is connected, and we find operating the principle of duality.

> Ces interrupteurs sont choisis suivant un principe de dualité : pour exprimer que deux parties d'un graphe ne communiquent pas, on les force à communiquer en un point, pour exprimer que ces deux parties communiquent, on empêche la communication en ce point. Le principal théorème de s'énonce alors :
>
> *Théorème 11.* Un réseau est séquentialisable ssi quelque soit la position de ses interrupteurs, le voyage n'a qu'un cycle (absence de court-circuit).

The absence of the "short circuit" or in other terms, the good communication between proofs, becomes the principle-guide for the construction of a proof net. In fact, from the dual point of view, linear logic discovers that the verification of the proof, thus the fact that it is a good proof, is its capacity to "communicate well" with other proofs. As a consequence, the geometrical property of the proofreading (a-cyclic and connection) becomes the geometrical translation of the test that the proof is able to communicate well with other proofs.

Logic duality becomes evident when treating the point of view of the interaction between proofs and their dynamics. In brief, the duality of a proof means the presence of two alternatives points of view under which one can express or consider the proof (Abrusci, 2009). Two propositions *A* and *B* are dual with respect to a couple of alternatives points of view, when they express the same content, but one (*A*) from a point of view and the other (*B*) from the opposite one. The interaction here indicate that the two proposition or "agents" respectively exchange something without establishing which one of them is the active (premise, hypothesis or input) and which one is the passive (conclusion or output). This possibility of exchanging references and this dynamic interrelation between subject and object, input and output, or individual and environment is in my opinion a precious key also for discussing living beings' functioning, as I've tried to illustrate with the biological examples discussed in previous section.

From another standpoint, as we have already seen, linear logic discovers a polar tension of logic operators and proofs by means of the power of the negation. The axiom *A* or negation of *A* (principle of the excluded third) is the interaction between a proposition and its linear negation: if we have the refutation of *A*, then we have the negation of *A*, if we have the refutation of the negation of *A*, then we have *A*. The dynamic or *communication* between the propositions is the occurrence of the interaction of *A* and its negation, not *A* (Abrusci, 2008).

In this way, linear logic highlights that the communication or the interaction between proofs is a process: the *history* of the development of the interaction by means of the expression or the use of *A* and its negation, not *A* by the two opponents. It describes how the two processes, the one that produces *A* and the one that produces not *A* are developed and transformed (Abrusci, 2008).

This focus on dynamic, procedure, updating and inheritance, which are the main features of linear logic programming (Girard, 1995), is in our comprehending very tuned with the "logic of life", differently from the logic-tool kit that Nurse was describing (see previous chapter) and which were based ona traditional logic account, based especially on linear determination.

We may add, in conclusion, that the "revolutionary" feature of linear logic is its focus on the idea of symmetry[210]. We see here a permeation among duality, symmetry and negation. We comprehend in fact that the entry and the exit of a proof-net have a symmetrical structure, which at the same time is dual by means of the negation.

And one should add (for symmetry) that there are also ruptures of symmetry. Girard (2009) for example explains that while Gentzen's methodology had introduced a symmetric formulation of axioms and of logic rules (sequent calculus), he himself has further introduced an asymmetric interpretation of Gentzen's works (1976)[211].

> Gentzen a introduit une formulation symétrique des axiomes et règles de la logique, le calcul des séquents, pas très utile pour écrire la logique, mais essentielle pour l'étudier (un peu comme les

[210] This remark is a suggestion of Giuseppe Longo who has known Girard's theories in the 80's, from the very beginning of it and in their first formulation.

[211] Three-valued logic and cut-elimination : the actual meaning of Takeuti's conjec- ture. Dissertationes Mathematicæ, 136 :1–49, 1976.

> équations de Hamilton en mécanique, qu'on utilise peu en pratique, mais qui permettent de poser les problèmes de facon abstraite). (Girard, 2009, p. 13).

We may understand the importance of symmetry and anti-symmetry in Girard's way of thinking also from what follows.

> Cette formulation lui permit de démontrer (en l'absence d'axiomes) ce qu'on pourrait appeler un principe de pureté des méthodes, à savoir que pour démontrer A, seulement les sous-formules de A sont nécessaires. En particulier, si A a un contenu finitaire (sans quantification universelle), A se démontre sans quantificateurs universels, c'est à dire par un calcul fini. (Ibidem)

This argument of purity of methodology is an internal feature of linear logic, and the principle of symmetry, expressed by physics' theories that in fact are always recalled by Girard, corresponds or incarnates itself this exigence of purity.

> L'idea sarebbe di pensare la logica in rapporto a quel fenomeno ignorato e disprezzato dai logici che è la fisica quantica. Almeno immaginare dei fondamenti con uno spirito quantico: tenendo ogni proporzione, un po' quello che fa Connes con la geometria non commutativa. [...] Invece di interpretare la quantica nella logica, si vuole tentare l'opposto. [...]. L'idea di un'altra regolarità, di un'altra logica che vive la sua propria vita, la sua propria geometria, fuori da ogni quadro [essenzialista] cascato dal cielo, come il monolite di "2001". Come dice Blaise « si ca marche, c'est tout bon, et si ne marche pas, on n'a rien perdu » (Girard, 2006, p. 12).

Girard appreciate the purity of the method of symmetry that for instance has allowed Gentzen to describe its calculus by means of only *internal* procedures (see above). We have discussed that the problem of Gentzen's method was situated instead at the level of the complicated technique that reintroduced in a sense an infinite procedure in the finite calculus and in the purity of methodology. In addition to this methodology, Gentzen had created also a mechanical procedure, named *cut-elimination* that, again by means of the symmetry of the proof, allows to substitute whatever proof by means of another one that verify itself that same property. Here again we remark the ideas of a procedural nature of logic and of proofreading which allow to discover also the exchangeability of the objects (proofs).

> De nos jours, on peut donc voir une démonstration abstraite comme un programme, que l'on calcule par élimination des coupures. Par exemple, le programme énonce l'existence d'un entier vérifiant une propriété finitaire, et l'élimination des coupures nous donne sa valeur. (Girard, 2009, p.13).

In this way the abstract proof can be interpreted as a concrete program that follow the calculus by means of cut-elimination procedure (Girard, 2006).

VIII.

I propose a sort of parallel between the property of exchangeability of proof-nets put in evidence by linear logic and the plasticity feature of biological processes (phenotipic plasticity which is the ability of an organism to change its phenotype in response to changes in the environment; homeostasis and homeorhesis are responsible for the regulation of the dynamics equilibria in the individual's life) (Buiatti, 2000). Moreover, “redundancy” and its dual “degenerescence” are both very important features of living systems that have been recently rediscovered also in a deterministic-approach discipline such as molecular biology. The original idea about genes, proposed by Central Dogma (1958), established that a gene controls one and only one expression of a protein at the time (we can recognize the linear causation), which was expressed by the slogan “one gene one protein”. In this sense the information contained in the alphabet (code) of four letters of the DNA was truthfully transcribed in the alphabet of RNA, again of four letters (even if slightly different because instead of thymine there is uracil). This same information was translated again in a new language that of proteins by means of the twenty elementary amino-acids. The translation according to the Dogma was exact because every amino acid corresponds to three RNA bases and thus to DNA (codons). It was later discovered that three of the sixty-four codons do not correspond to an amino acid and work as the signal “stop” meaning the end of the coding region and all the other sixty-one are redundant, because being amino acid only twenty every amino acid is coded by more than one codon (thus the code is degenerated) (Buiatti, 2000). Characteristics those that are complete non-sense in a programming code (see Longo's discussion in previous section). More recently geneticists have discovered the properties of pleiotropy and pleionomy of genes. Pleiotropy stands for the fact that a same gene may regulate the production of different proteins, while its dual characteristic is pleionomy: a same protein can be produced by different genes (Buiatti, 2008). And this is possible not only at the genes-protein level, but also at different hierarchical levels, as we mentioned above in the discussion of S&S proposal. All these characteristic suggest a more general principle of living beings' organization.

> Les effets synergiques de mutations différentes, qui modifient le cours du développement, en interférant sur les mécanismes de stabilisation et de fidélité dans la transduction des signaux de communications intercellulaires dans les tissus embryonnaires en cours de différenciation, donnent un substrat moléculaire aux intuitions anciens d'un richard Goldsmith sur les Monstres pleins d'espoir, toujours rejeté dans le cadre de l'ancien paradigme. (Atlan, 1999, La fin du «tout genetique » ? vers de nouveaux paradigmes en biologie, INRA editions, Paris).

As Atlan remarks an organism is continuously affected by synergic effects that creates a perturbation, although at the same time these disturbs allow the individual's life. The fundamental property of redundancy which opposes to structural stability (Bailly-Longo, 2010), shows again a duality:

> On retrouve le même mécanisme dans d'autres processus de différenciation ou un "bruit développemental" contribue a créer de la diversité et de la spécificité en diminuant une redondance initiale (Ivi, p. 28).

As Atlan explains the redundancy, in spite of generating chaos, or a "bad communication" among different elements is at the base of the variety of life. But again, for symmetry there is something that opposes to a repetitive, infinite variability. In fact it is the selection itself and, errors, deaths, extinctions that prevent an “infinite” proliferation of variability. We may hint only in a suggestive way that in linear logic's terms this process can be seen as the property which includes the infinite in a finite structure. And we may underline just as a suggestion for future research an analogy with Girard’s idea of the internal completeness of logic methodology and of its objects which are “cyclical and connected”. In this way the property of “well communicating” of the proofs is analogous to the plasticity features of the individuals to which me made reference above (phenotipic, homeostasis and homeorhesis) granting stability through the continuous instabilities of individuals’ life. And we have already mentioned in chapter two the “going wrong” feature of living matter: evolution takes place due to errors and the memory of errors (onthogenesis and phylogenesis)[212]. One of the most beautiful paradoxes of the irredeemability of life stands in the contrast between the impressive and *infinite* variability of life with the structural stability of the *finite* life of the individual. And one may hint that linear logic has a peculiar opinion about the relationship between infinite and finite in logic constructions.

This polarity can be underlined, as we have discussed in previous section (chapter one and two) also for the concept

[212] One may recall also the ago-antagonist processes put in evidence by Bernard-Weil (2002).

of interaction. It does not exist an interaction, which is not also an interference, inside or outside the organism. One should recall also the example of a virus attacking an organism, their behavior describe a duality: what is wrong for one is good for the other and vice versa.

This dual perspective, which is at the core of living being dynamics can be better interpreted by the properties underlined by linear logic; such as "linear logic" determination that expresses a continuous possible dynamic of proofs that are themselves characterized by their geometry and symmetry properties. This contributes to put in evidence a peculiar *plasticity* of proof nets, which is in my opinion more tuned with the typical plasticity, or redundancy, of living beings (Berthoz, Petit, 2006; Buiatti, 2000) rather than a typical lineary deterministic standpoint.

Contrarily to linear causality, which dominates both in some physical interpretations and in classical logic, duality and symmetry properties at the base of linear logic procedure, allowing to proceed in a non-strictly deterministic modus operandi.

We may add, as a conclusion one last important remark.

> La logique linéaire apparaît dans l'article [27]. Elle se distingue de la logique usuelle en ce qu'elle est basée sur de nombreux petits connecteurs qui ont une signification en termes de ressources. Par ressources, on entendra aussi bien de l'argent que du temps de calcul ou encore de l'espace mémoire. (Girard, 2009, p. 19).

I have already mentioned the importance of the consideration of use and incarnated elements of the proof. One of the great discoveries of linear logic is proceeding onto the way of the connection among proofs, programs and systems. The base of this relationship was discovered in the so-called Curry-Howard correspondence[213].

Linear logic deepens the correspondence giving to it a new finer analysis.

> L'article [30] (avec Y. Lafont) posait les bases d'une nouvelle gestion de la mémoire au moyen de A ! B ; en particulier, il devient possible, grâce aux informations supplémentaires sur l'utilisation de la mémoire qu'apporte la logique linéaire, de savoir quand une case mémoire ne sera plus utilisée, et donc de la récupérer.
>
> Plus généralement la logique linéaire semble s'appliquer dans d'autres domaines de l'informatique ; une des données essentielles des problèmes informatiques est la possibilité de révision, à la différence des mathématiques où les acquis ne sont (en principe) jamais remis en cause. C'est que nous parlons *des états d'un système en constante évolution* ; si on cherche à les décrire avec des formules logiques, il va tout simplement arriver qu'un état ultérieur soit en contradiction avec l'état présent.

From the connection among proofs, programs and systems one clearly can see the emergence of the trait that interest us here: the constant evolution of a system. As Girard says above, holding to a classical logic point of view it may occur that a peculiar state of the system becomes in contradiction with its subsequent. As in fact I have remarked talking about the importance of a non-only-linear determination of interaction.

---

[213] Haskell Curry and William Howard's two-step discovery, in 1958 and 1969 respectively, of the correspondence between λ-calculus and natural deduction, which recalls their names.

La logique classique, qui est basée sur un principe de pérennité de la vérité (ce que j'ai, je le garde, que je l'utilise ou non) est mal adaptée à cette situation nouvelle ; il en va de même de la logique intuitionniste. Par contre la logique linéaire, qui efface (en l'absence de "!") les formules utilisées, se prete tout naturellement à la révision. (ivi).

Critical appendix:

1. Some epistemological remarks on the procedural point of view

I.

One of the problems of nowadays dialogue between sciences is the increasing tax of specialization of the disciplines which creates an obstacle for translating local researches, proposed in different disciplines, into global systems. We have tried also to assume this as a specific problem:

- I have preceded analyzing and clarifying some selected concepts, respectively in physics, psychology, neurosciences, biology and linear logic.
- On the basis of what I have found out I have discussed the possibility of some simplified common traits between the different disciplines.
- Finally, on the basis of this clarification, I would hope to help in supporting a concrete exchange, between biology, logic and philosophy.

Another remark that I would like to put in evidence is that science operates on the basis of a two-faces process: a great incoming production of researches and the stratification of knowledge, thought and theories through different epochs. Some ideas of the past have been shadowed by dominant cultural paradigms, even if some of them have been rediscovered at the light of recent discoveries due to their consistence and their innovating character (Canguilhem, 1952; Fox Keller, 2002).

I think that a proper guideline for developing nowadays an epistemological thought which aim is focusing a relation between disciplines consists in the individuation of a way of access to the problematic knots of classic paradigms. Linear logic offers an example of a concrete procedure to re-examine and “refine” classical paradigms, either if we consider linear logic as an operation of “deconstruction” of classical logic or as an “analysis at the microscope” of classical logic (Girard, 2006).

In our opinion, this kind of epistemological approach which looks for extension of traditional paradigms is in accord to (Bailly-Longo, 2010) approach in theoretical biology. According to this standpoint we don’t have to introduce something from the exterior to present theories, respectively in Logic and in Biology, but we can merely change the point of view by which we develop the researches. Or in other words, we can search for extensions of present and classic theories that won’t invalid them, but that, whenever this might be useful, would be consistent with previous theories and at the same time innovative.

The characteristic Girard’s idea (and what Longo and Bailly assumes for the conceptual oppositions physics vs biology) that I may take as a methodological reference of research is that it is possible to create a modification from the inside of present paradigms due to their widening. Or in other words, it is what Girard names the problem of “finesse” concerning the question about foundations from a logical point of view. This “refinement approach” has been shadowed and neglected in Twentieth century Logic researches (Girard, 2006). Beginning from 1985, in the middle of the “informatics revolution”, Linear Logic has been conceived by Girard with this peculiar character of refinement of classical theories that allow keeping at the same time an aspect of continuity and one of renovation regarding traditional theories.

I have tried to keep this idea of “evolution”, “extension”, “exaptation” as a global standpoint to proceed in my analysis. In fact, from the very beginning of this work I have selected and privileged in the same way texts and reflections from the very beginning of philosophy and history of science, such as the Greek atomic theory, while at the same time I’ve tried to put into light their possible “interactions” with modern and nowadays ideas. That is in fact, one of the reasons for my peculiar interest in this work in texts that were conceived just after World War II, in an epoch that was rich of implicit developments and prosperous of thoughts.

II.

The second methodological idea of linear logic that I consider relevant for my purpose is that objects definitions are not given in function of their essence, but in function of their behavior inside and towards the system. Briefly, an essentialist approach is substituted by an existentialistic standpoint (Girard, 2006). The existence is created by the interaction between parts of the system (or the proofs, or the programs), while the essence is a list of properties, axioms and rules. "Manipulating" the essence it is possible to find existence; and this is the core of the meaning of the procedural approach.

This very point of view is the one that I've tried to keep in this work to gain a "definition" of living beings: there is not an essence of living beings that can be obtained through a list of properties (Longo, 2008). Living beings and individuals don't have a proper definition as an essence, but they manifest their existence through their complex processes of maintaining life alive.

In Girard's opinion the essentialist approach consists in considering objects as data, given to us by an inexplicit source, as a sort of archetypes. We have already mentioned Husserl's idea of the naturalistic approach (1912), and its critic about how generally science considers as data the objects of its world, without asking itself about their existence (chapter one).

In Girard's thought the only way that has been employed to justify this kind of objects is the strategy of the upside-down foundations, or, in other words, the fact that a system is defined on the basis of a meta-system which in its turn is defined by a meta-meta system, in a perpetual regression to infinity (Girard, 2006). While existentialists' point of view is that every law has its value only when it is justified: this means showing the effect of its non-observance. In its turn this implies a concept of non- tautological truth that needs a continuous process of verification; or in Girard's "the idea of a world where the checkout is total and constant" (Girard, 2006).

A consequence of this approach consists, for instance, in thinking the interaction of the two points of view (essentialist and existentialist) and not giving form to theories on the basis of their rigid opposition; this very approach would in fact presuppose an hypostatization of the two points of view and would be in its turn intrinsically essentialist (Girard, 2006). So the idea, again, is to assume a procedural approach: keep together the two points of view that can appear opposed at first sight and work on their interaction and reciprocity without considering their objects or theories as given data.

If we move on the field of Biology we can enlighten a similar idea of dynamical interaction that can be described in different constitutive levels. For instance, if we keep the point of view of the temporality we can distinguish:

- The constitution of the organism; the way by which the complex organization of organism is attained in different levels regulated and integrated among them and in its continuous interplay (Bailly, Longo, 2010).
- The maintenance of the organism; the temporal extension of

organism's life.

- The interaction between a physics general temporality and the specific temporality of the organism (Longo, Montevil, 2011).

This gives a picture of a living being on one hand characterized by the idea of a dynamics-interaction between itself and its constitutive parts and on the other, between all living beings, their belonging ecological niche and global environment (Gilbert, 1999).

Trying to resume this process in a frame we find a double movement: towards the inside of the organism and towards exterior life, which nonetheless is always in a quivering state (Frezza, Longo, 2010). To give another picture of this one may refer to Husserl's analysis of the constitution of perceptive experience. In particular in *Ideen* (1912) and *Ding und Raum* (1904-1905) Husserl describes the difficulty of a phenomenological description of life and conscience phenomena. The reference of analysis is the distinction in different levels of the experience constitution. These levels or *grades*, as we prefer to refer to them, are distinguishable only in a descriptive attitude. In their very process all levels of constitution (the thing, the kinesthetic, the movements, the vision, the individual and the inter-subjective consciousness etc.) are integrated and continuously going one into the other without any interruption (Frezza, 2007).

I may define, then, also my epistemological approach procedural because it focus on the analysis of these concepts in their dynamics-interaction and in their constant development; following the articulated net of relations involved in studying the peculiar phenomena of living beings.

2. Some brief remarks about scientific language

A core element of my analysis is the notion of scientific language. In particular I focus on the relation between a specific scientific language, result of technical concepts stratification and selection proper of every science and the necessity of a global integration and a conceptual opening between similar disciplines languages. This element of analysis of my thesis has emerged in reason of the difficulty of keeping together local order of specific notions with global questions arising in the researching field.
An example of this problem has been recently put in evidence by "glo-cal" mirror neurons studies which have introduced technical and scientific notions into general philosophical and psychological questions about human motor system and empathy (Rizzolatti, Craighero, 2004; Gallese, 2006). In this case, it can be enlighten a sort of bidirectional dialogue that goes from neurosciences towards general questions of philosophy, psychology, art and more recently psychiatric and medical domain and vice versa neurosciences point of view has stimulated new research fields in the other disciplines. In our opinion, to stay at this language thematic subject, the employ of a famous

metaphor, as that of the *mirror*, has been a powerful tool for diffusing mirror neurons studies (Frezza, 2009). Nonetheless, metaphor use as technical science language seems to escape easily away from standard scientific norms (Fox-Keller, 2002); using metaphors without loosing scientific rigor requires strong mathematical evidence behind (Longo, Frezza, 2010).

Another example of the problem of crossing languages, which I discuss in the present work, is the possibility of giving a correspondent *physic* explanation to *biological* phenomena as *peculiar physical living systems*. I would love to enlighten the perspective from which, in my opinion, this correspondence could be made. Is not the case of a "reduction" of biology into physics, for instance, in the sense of the physicalist reduction paradigm[214]; or of a simple transfer from one discipline to another; rather, I support Bailly-Longo's (and Girard's) standpoints of an *extension* of physical present theories that could respond to the peculiar terms of living beings (Bailly, Longo, 2010). Is a change of perspective, or, as we put it before in Girard's words, a "refinement from the inside". In the analysis of some case-studies (chapter two) I found out that the core question is to keep the conceptual specificity without loosing the possibility of a crossed description, whenever this possibility would seem a relevant and useful.

[214] Neopositivism physicalist and logicist paradigm and its highs and falls in the last century are still a subject of debate that is not our primary concern in this work. For a selected overview on the argument: [Carnap, 1928; Jorgensen, 1958; Feyerabend, 1962; Nagel, 1970]. For a specific discussion of biological reduction see previous chapters.

Conclusions

In this work I have discussed a possible (hi)story of the concept of interaction which outlines what I called its *epistemological exaptations* throughout different years and disciplines. After a brief analysis of the use and diffusion of the concept in various scientific disciplines I have noticed an intense and extensive growth especially within the last thirty years (‘80s-‘10s, see “Introduction”, table 1). More properly, I have delineated two different tendencies: a horizontal “ext-ensivity” (diffusion) and at the same time a vertical “int-ensivity” (frequency) when considering the increasing in its employment throughout the years.

Starting from these considerations, I began to reflect on the possible conceptual evolution of the term. The first analysis (see “Introduction”, table 1 and 2) has put in evidence a specific ground of development in physics and in psychology especially from the ‘30s-‘40s. Therefore, I have decided to look more in detail at physics and psychology’s researches of those years, which may outline a sort of theoretical cradle of the concept (chapter one).

In particular, concerning physics, the concept of “interaction” is strongly connected with that of “force” (the fundamental interactions related to the four basic forces of physics —gravitational, electromagnetic, strong, and weak). This link led me to individuate a conceptual family which embraces the ideas of "interaction", "force", "action" and "particle". In this way I was able to follow a line of discussion which, starting from the ancient Atomist description of atoms and their aggregation-interaction, brought to the development of the complementarity principle and new quantum mechanics ideas discussed in a philosophical perspective by Heisenberg (1958).

From these reflections, among many ideas, clearly emerge the notions of interplay, interference, local-global correspondence and the opposition of objectivity and subjectivity, all keys of the development of the concept of interaction. I advocate that, from this point of view, the interaction results a process due of a polarity, opposed to the idea of a linear determination (one cause produces one effect). The interaction has a "positive pole", being the coordinated action between two objects, while at the same time it has a "negative pole" being the interference, or the perturbation, in the development of the actual process. This duality correlates in a unique perspective the local properties with the global ones, the measure of the object with the object itself, the subjective standpoint with the objective one. The polarity, which introduces an uncertainty in the traditional idea of "objective knowledge", is a theoretical "novelty" suggested by physics which has established relevant philosophical consequences and a revolutionary key of interpretation of the reality. Paradoxically, the duality (which is not dualism) between the subjective standpoint and the objective one allows to consider them linked in an interactive way rather than linearly opposed in a classical dualistic determination.

In these analyses therefore I have identified two different matrices, or a *double lineage*, of the concept of interaction: a linear-deterministic origin and a multi-factorial non-deterministic one. The first is grounded in the ideas of particle, number, quantity... which all together give birth to one approach that is strongly deterministic and which today's one would call "analytical". Another direction, instead, focuses on the criteria of random, multifactorial, complexity, interference... delineating a way of thinking which one may rather name "synthetic". In this way, my work develops an epistemological direction of research which puts in evidence and follows the interplay of these two approaches concerning the concept of interaction, understanding some fundamental differences in its meaning, its employment and their consequences in scientific analysis.

To unravel and describe the second idea ("synthetic") I have selected Gestalt theory's approach (*GT*) in psychology, especially considering some of Köhler's main ideas (*e.g.* 1929; 1938), which has been inspired by physics researches on field's interactions and which has shed light on the organizational process in visual perception. This approach, in my opinion, may offer a singular point of view in describing living beings' matter too.

The *Gestalt* is an organized structure, used not only to mean the result of an organizational process, but also to represent the structural properties of the process itself, distinguishing it from mere juxtaposition and casual distribution in the visual field. It is a "proper" interactive process. The exchange between "figure" and "ground" in a *Gestalt* establishes a specific *constraint* between local and global properties that I find also very appropriate for considering theoretically living being phenomenon of constraint (Gould, Lewontin, 1979). In addition to that, I think it is remarkable and heuristic the way *Gestalttheorie* talks about the interaction in a field as an act of organization and discrimination at the same time. Again, as we have seen in physics, and very closely to the biological notion of constraint too, depending from the standpoint one looks at it, one interaction is also an interference and at the same time a selection among an infinite potentiality of possible determinations.

The importance of potentiality withrespect to actual determination is well known in philosophy (Debru, 2003) and in biology (Jacob, 1981). The process of discrimination "makes" the reality of the thing (the appearance of the *Gestalt*), just as in physics the measure gives the existence of the trajectory of the particle.

Moreover, another reason for my interest in *Gestalttheorie*'s proposal is because it stands in between a strictly mechanist standpoint and a vitalist one (Kohler, 1938), suggesting the idea of a "qualitative science". I believe this attitude is worth to be considered when one wants to take into account living beings' phenomena from a theoretical point of view. And it is easy to see that as a reflect of this approach *Gestalttheorie*'s concept of interaction shows and beholds a polarity too.

At this point of my research, therefore, I was led to ascertain that both representations, or way of thinking, the concept of interaction (linear-deterministic and synthetic-multifactorial) influence its development or its *exaptation* in biological field. I have selected four main case studies (Nurse's information flow, Bailly-Longo's conceptual dualities, Berthoz-Petit's crossing points of view and Soto-Sonnenschein's researches on cell proliferation and cancer) which, in my opinion, particularly allow to put in evidence this double/crossed use of the concept of interaction.

In fact all the case studies show a peculiar philosophical interest (not to say, even a philosophical aim) and develop an interdisciplinary approach. In particular the first (Nurse) focuses on the possibility of a crossed logical-biological horizon, the second (Bailly-Longo) individuates some conceptual dualities between biology and physics theoretizing, the third (Berthoz-Petit) analyzes neuroscience researches about visual and motor perception by means of a phenomenological insight, yet the last one (Soto-Sonnenschein) sustains the establishment of a hierarchical level of organization for analyzing living beings' phenomena. In brief, all these researches are made in the direction of a synthetic approach which at the same time would not neglect the focus on interaction. And moreover, the interaction is not only intended as subject of research, but also as a methodology. I have named this way of thinking and theoretizing characterized by a "twist of interaction".

By virtue of the analysis of these four case studies I have been able, then, to better understand and shed light on the peculiar polarity of the concept of interaction in biology. The consideration that I have proposed is that this polarity would be deeply intrinsic to the practice and analyses of biology. In fact, from an historical point of view one sees the traditional development of biological thought by oppositions (Canguilhem, 1952), and for instance the interplay between genetics and epigenetics can be considered an emblematic example of this (Buiatti, 2008). In genetics' field, and in particular recent epigenetics' developments, has been clearly put in evidence the relevancy of a double perspective in the functioning of the DNA's activity and regulation, which gives a more comprehensive idea of living beings' dynamics. In fact, from the "stasis" of the 50s, dominated by Central Dogma hypothesis (which as every dogma, was much more considered as an imposition rather than such as an hypothesis) recently one has passed to a more wide-ranging horizon which should encompass both way of thinking (genetics and epigenetics). By virtue of new and continuous amount of experimental researches, we can already try to find a more complex way of re-thinking those conceptual oppositions that have divided entire generations of scientists (mechanicism vs vitalism,discrete vs continuum, necessity vs random,simple vs complex,genotype vs phenotype, body vs mind, identity vs plurality, fixity vs evolution, independence vs interaction...). The individuation and the discussion of the polarity of the concept of interaction might be considered a step in this direction.

On this line, there is another element which I have underlined in my work: when one looks at this polarity from an epistemological point of view it recall itself a traditional way of thinking by oppositions, or antinomies. This attitude, which William James described with a metaphor, is the result of the "great splitting of the whole universe into two halves [...] and for each of us almost all the interest attaches to one of the halves; but we all draw the line of division between them in different places" (James, 2007 [1890] p. 289). The polarity of interaction, conceived from this standpoint, is a reflect of the ancient debate between mechanism vs vitalism, which at the same time is the twist of a more ancient debate about determinism or indeterminism, atomism or holistic standpoint, subject versus objective point of view. Or in other words, emerges the outline of an "ancestral", perpetual, multi-significant and multi-stratified dispute which brings all the various aspect of a research to the border line of a simple theoretical choice as James has explained.

The main difficulty that I have underlined in the mechanist approach is the misleading reasoning by which mechanism, such as the stimulus-response model of behaviorism (Skinner, 1953) does not foresee that the instances of local sensory data depends upon the relation between local stimuli and stimuli in their neighborhood. This approach therefore use as model of reference the "universal subject", which, I may say, rather than "incorporated and living" is "abstract and alive". This perspective is very inappropriate to reach the complexity of living beings' experience, which is incorporated and "lived". And it is opposed for instance to Berthoz-Petit's (2006) phenomenological proposal of grounding the individuals' experience in the capacity of exchanging points of view of human beings.

In order to sketch a theoretical outline, which could encompass both the opposed approaches (mechanicist and vitalist or analytical and synthetic), I propose to assume the polarity which in itself is a "natural" phenomenon and thus, a "natural" way of thinking too, as a proper instrument of analysis. To this extent, I have found in Vigotsky's historical approach to the mind a privileged tool apt for this purpose. Vigotsky's focus on the interaction between historicity and culture and their interplay with brain-mind evolution could help to delineate a solution to the a-historicity of the universal subject.

On these lines, I have proposed with my work a theoretical direction which goes underneath the investigation about the "epistemological exaptations" of the concept of interaction and which takes into account and assumes the "epistemological culture" present in every scientific research as a relevant feature for the analysis. In the lines of a flourishing field of studies, especially grounded in France (Bachelard, Canguilhem, Althusser, Foucault), I have modestly tried to emphasize the peculiar crossovers among disciplines, culture and scientific way of thinking present in the texts and in the researches that I have discussed in my investigations. In this sense, I have delineated in the '50s a peculiar ground of development of some main ideas which are at the basis of the further "exaptations" and debates between the "analytical" and the "synthetic" approaches.

I have concluded that to get along with these polarized-standpoints in research it might be useful not to choose inevitably for the one or the other pole, but rather to stay and assume their dynamics, with a "twist of interaction", which means necessarily with an open interdisciplinary eye. In an interdisciplinary direction, the last part of my work has tried to suggest also an analysis of the interaction from a logic standpoint. I have established a possible parallel between the analyses about interaction made in physics, psychology and biology and those achieved by logic, in particular linear logic and "Geometry of Interaction" approaches (*e.g.* Girard, 2009). I found useful and interesting to better understand the ideas of interaction and its polarization from the point of view of logic too, as a sort of clarification which could better delineate the logical underpinnings of this polarity.

Linear logic and especially "Geometry of Interaction" suggest a flourishing line of research in this direction. The analysis of the concept of interaction from a logical point of view, clearly shows that the traditional logical ideas of causality and determination are "mechanical", or "imposed from the exterior ". In a sense this vision recalls the point of view of physics which proposes that causality is something strongly connected with the idea of prediction. In the field of biology these main criteria do not work "at all". We have already touched this argument when treating biological versus physical conceptual oppositions (chapter two).

It is possible to hint a parallel with the organizational process and hierarchical standpoint about the organism and the dynamics proper of proofs and proofreading developed by linear logic. The description and the development of proofnets in linear logic is not conceived by means of the traditional distinction between semantic and syntactic apparatus.

> La logique classique portait essentiellement sur la transmission de valeurs de vérité, et exigeait comme condition de possibilité d'une théorie de la démonstration que la vérité soit conservée dans toutes les opérations logiques possibles. Un tel système n'est pas très difficile à obtenir, les logicistes, et Tarski en particulier, ont bien formalisé cette exigence en promouvant un cadre déterministe et calculatoire à une telle logique des valeurs. (Tronçon, 2006).

Traditionally, when manipulating the syntax (formulas, proofs, ...) via rewriting procedures, one obtains just a formal dynamics, as we have seen (Girard, 2009). On the contrary, in GdI the dynamics pre-exists and the syntax (formulas, proof, ...) becomes only a "commentary", a label, of the "quasi-physical objects" which have their proper dynamics, and not the *motor* of their dynamics.

> Il s'agit ni plus ni moins que d'expulser totalement la syntaxe de la description des démonstrations pour les remplacer par des opérateurs. (Girard, 2009, p. 22).

The element I have stressed is that GdI does not describe "existing physical interactions", as in the idea of a syntax that describe a semantic, because GdI comes out from a physical reference itself, "mon intuition méthodologique est physique" (Girard, 2009, p. 2). Another possible commentary is that this approach is tuned with what we have said about Vygotsky's historic way of thinking culture and behaviors. In fact, it allows to carry on a complex, interactive and living idea of cognition, and more generally of human practices. Again, taking into account the importance of historical and evolutionary criteria, which is not very common in logic attitude, requires to break with a linear concept of determination. This fracture may imply also to eliminate the idea that something is made forever; even a theory or a calculus is subject to modifications. The analysis that linear logic makes of calculus, proofnets and proofreading focusing on the criteria of procedure, history, and development is very adequate to represent the dynamics of living beings' phenomena.

The oppositions that have been put in evidence (quantity-quality, determinism-indeterminism, analytical-synthetic...) in the case of the description of the organism could be solved by virtue of the polarity of the organism's life in itself. The maintenance of structural stability through variation, "variability" as the main actor of living phenomena, together with mutations and multiversity of life demonstrate directly this possibility, even if we are not able to understand it...

> I sistemi viventi sono enormemente diversificati durante l'evoluzione ed hanno adottato startegie di adattamento molto diverse. Non puo' quindi ragionevolmente esistere un'unica teoria dell'evoluzione che tenga conto contemporaneamente di tutte le facce della multiversita' biologica se non la si basa sull'accettazione del sincretismo reale della vita, che per restare tale ha inventato e sta inventando nuovi strumenti e nuovi processi di adattamento. E' d'altra parte comprensibile e tipicamente umano il desiderio di conoscere tutti gli oggetti sottoposti alla nostra osservazione e comprenderli in leggi "universali" che ci permettano di prevedere le dinamiche ed eventualmente modificarle a nostro favore. Buiatti (2008), p. 79.

Bibliografia

Abrusci V.M. (2008), “Remarques sur la philosophie et l’histoire de la logique à la lumière de la recherche logique contemporaine”, Conference at the Sorbonne University, 20th of february 2008.

Abrusci V. M. (2009), Logica, Cedam, Milano.

Alberts B., Johnson A., Lewis J., Raff M., Roberts K., Walter P. (eds.) (2002), *Molecular Biology of the Cell*, Garland Science, New York.

Andler D., Fagot-Largeault A., St Sernin B. (2002) *Philosophie des sciences Tome 1*, Gallimard Paris

Aristotle, Works. Translated into English under the editorship of Ross W.D. (1908) Vol. II, De Caelo; De Generatione et Corruptione, Oxford Clarendon Press, Oxford.

Ash M. (1998), *Gestalt psychology in German culture, 1890-1967*, Cambridge University Press, Cambridge.

Bachelard G. (1940), *La philosophie du non: essai d'une philosophie du nouvel esprit scientifique*, Puf, Paris.

Bailly F., Longo G. (2008), “Extended Critical Situations”, *Journal of Biological Systems*, Vol. 16, No. 2: 309-336.

Bailly F., Longo G. (2010), *Mathematics and natural sciences. The physical singularity of Life*, Imperial College Press/World Sci. (preliminary version, in French, Hermann, Paris, 2006).

Bailly F., Longo G., (2009), “Biological Organization and Anti-Entropy”, *Journal of Biological Systems*, Vol. 17, No. 1: 63-96.

Bailly F., Longo G., (2010), *Mathematics and natural sciences. The physical singularity of Life*, Imperial College Press/World Sci. (preliminary version, in French, Hermann, Paris, 2006).

Bailly F., Longo G., Montévil M., (2010), *A 2-dimensional Geometry for Biological Time.* Invited Lecture, conference “Biologie e selezioni naturali”, Florence, December 4-8, 2009 (see http://www.di.ens.fr/users/longo/).

Bak P., Tang C., Wiesenfeld K. (1988), “Self-organized criticality”, *Physical Review,* A 38: 364-374.

Balibar F. (1992), *Einstein 1905. De l’ehter aux quanta*, PUF, Paris.

Benveniste E. (1969), *Le Vocabulaire des institutions indo-européennes*, vol. 1-2, Minuit, Paris.

Berkowitz J., Hemmo M. (2006), “A new modal interpretation of Q.M. in terms of relational properties”, *in* Demopoulos W., Pitowsky I. (eds.), *Physical theory and its interpretation. Essays in honor of Jeffrey Bub,* Springer, Dordrecht.

Bernstein N. (1967) *The co-ordination and regulation of movements*. Oxford: Pergamon Press.

Berthoz (1997), *Le sens du mouvement*, Odile Jacob, Paris.

Berthoz A. (2006) et Petit J.-L., *Phénoménologie et physiologie de l’action*, Paris, Odile Jacob,.

Berthoz A., (2004) “Physiologie du changement de point de vue”, in Jorland G. (éd.), L’Empathie, Paris, Odile Jacob.

Berthoz A., Petit J.-L. (2006), *Phénoménologie et physiologie de l'action*, Odile Jacob, Paris.

Bitbol, M. (1996), *De l’interieur du monde (Essai sur la mechanique quantique),* Flammarion, Paris.

Bitbol, M. (2008), *Mecanique quantique. Une introduction philosophique*, Flammarion, Paris.

Black M. (1962), *Models and metaphors*, Cornell University Press, Ithaca, NY.

Blanchard R. (1941) “Necrologie: M. Lucien Gallois”, *Revue de Géographie alpine*, 29-3: 505-512.

Bohr N. (1920), "Über die Serienspektra der Element", *Zeitschrift für Physik,* 2 (5): 423–478.

Bohr N. (1999), *Causality and complementarity: epistemological lessons of studies in atomic physics*, Ox Bow Press.

Bohr N. (2008), “Complementarity Beyond Physics (1928-1962)”, in Aserud F. (ed. by), *Niels Bohr Collected Works*, Vol. 10, Niels Bohr Archive, Copenhagen.

Bozzi P. (1988), “Sugli antecedenti filosofici e scientifici della Gestalt-theorie”, *in* Kanizsa G., Caramelli N. (a cura di), *L’eredità della psicologia della Gestalt*, Il Mulino, Bologna.

Bozzi P. (1989), *Fenomenologia sperimentale*, Il Mulino, Bologna.

Buiatti M. (2000), *Lo stato vivente della materia*, Edizioni UTET, Torino.

Canguilhem G. (1952), *La connaissance de la vie*, Vrin, Paris.

Canguilhem G. (1955), *La formation du concept de réflèxe aux XVIIe et XVIIIe siècles*, PUF, Paris; 2e éd, revisée et augmentée, Vrin, Paris, 1977.

Canguilhem G. (1966), *Le normal et le pathologique*, PUF, Paris.

Canguilhem G. (2000), *Idéologie et rationalité dans l'histoire des sciences de la vie*, Vrin, Paris (ed. or. 1977).

Casini P. (1998) (ed. or. 1978) *Filosofia e fisica da Newton a Kant*, Loescher, Torino.

Cavazzini A., Gualandi A. (a cura di) (2009) *Logiche del vivente Evoluzione, sviluppo, cognizione nell'epistemologia francese contemporanea*, Quodlibet, Macerata.

Cavazzini A. (2010),*Dalla macchina all'organismo –e ritorno*, Gagliasso, Frezza (2010), cit.

Chalmers A. (1976), *What is this thing called science? An assessment of the nature and status of science and its methods*, Univ. of Queensland Press, St Lucia.

Conche M. (1989), *L'aléatoire*, Editions de Mégare, Paris.

Continenza B. (2008), "Evoluzione e sviluppo tra divorzi, sintesi e simulazioni" in Calabi L. (ed.) (2008), *Il futuro di Darwin*, UTET, Torino.

Darwin C. (1859), *On the origin of species by means of natural selection*, Murray, London.

Dazzi N., Mecacci L. (a cura di) (1982), *Storia antologica della psicologia,* Giunti Barbera, Firenze.

De Caro M., Mori M., Spinelli E. (2011), *Storia dell'idea di libero arbitrio*, Carocci, Roma.

Debru C. (2003), *Le possible et les biotechnologies*, PUF, Paris.

Debru C. (2004), *Georges Canguilhem, science et non-science*, Rue d'Ulm, Paris.

Debru C. (2010), "Metafore del cervello", in Gagliasso, Frezza (2010), cit.

Delbruck M. (1944), *Problems of Modern Biology in Relation to Atomic Physics*, Vanderbilt University School of Medicine Library.

Deleuze G., (1986) «Le cerveau c'est l'écran», Cahiers du cinéma, n°380, février 1986, p. 25-32 in Deux régimes des fous, Les éditions de Minuit, Paris, 2003, p. 265.

Demopoulos W. (2006), "On the notion of a physical theory of an incompletely knowable domain", *in* (eds.) Demopoulos W., Pitowsky I. (2006).

Dirac P. (1933), "The Lagrangian in Quantum Mechanics", *Physikalische Zeitschrift der Sowjetunion*, 3:64–72.

Domondon A. T. (2006), "Bringing physics to bear on the phenomenon of life: the divergent positions of Bohr, Delbrück, and Schrödinger", *Studies in History and Philosophy of Science Part C*, 37, 3: 433-458.

Eco U. (1989), *The Open Work* Harvard University Press, Boston (ed. or. 1962).

Einstein A. (1917/1961), *Relativity: the special and the general theory, a popular exposition*, Grown publishers, New Yourk.Einstein A., Infeld L. (1938), *The evolution of Physics,* Simon and Schuster, New York.

Encyclopedia Britannica, voice "Fundamental interaction", http://www.britannica.com/

Farber E. (1995) "Cell proliferation as major risk factor for cancer: a concept of doubtful validity", *Cancer Res.*, 55: 3759-3762.

Favrin V. (2010), "Modelli e metafore: una concezione costruttivista della conoscenza", in Gagliasso, Frezza (2010), cit.

Feynman, R. P., Hibbs A. R. (1965), *Quantum Mechanics and Path Integrals*, New York, McGraw-Hill.

Feynmann R. (2006), *The Feynman lectures on Physics*, California Institute of Technology.

Fine O. (1560) *Sphaerae Mundi. De Solirabus*, *in* J. Fine (éd.), *Abrégé des préceptes d'Algèbre* par J. de Billy, *Sphaerae Mundi. De Solirabus*, par de Fine, *Quadrati geometricus* de J. Demerlierium, *De usu geometriae* de J. Pelletan.

Fodor J., (1985), "Précis of The Modularity of Mind", *Behavioral and Brain Sciences, 8:1-5.*

Foucault M. (1966), *Les mots et les choses. Une archéologie des sciences humaines*, Gallimard, Paris.

Fox-Keller E. (2000), *Century of the gene*, Harvard University Press, Cambridge.

Fox-Keller E. (2002), *Making sense of life*, Harvard Univ. Press, Cambridge, London.

Frezza G. (2009), “La ricerca di un modello neurofisiologico per il rispecchiamento con l’altro: la polarità del Mirror Neuron System e il caso dell’autismo”, *Teorie & Modell*i, n.s., XIV, 1, (102-117).

Frezza G. (2010), “La metafora dello specchio e i mirror neurons”, in Gagliasso E., Frezza G. (a cura di), Metafore del Vivente. Linguaggi e sperimentazione in filosofia, biologia e scienze cognitive, Franco Angeli, Milano.

Frezza G., Longo G. (2010), “Variations on the theme of invariants: conceptual and mathematical dualities in physics vs biology”, *Human Evolution*, 25, n.3-4: 51-263.

Frezza G., Longo G. (2010), “Variations on the theme of invariants: conceptual and mathematical dualities in physics vs biology”, *in* Chiarelli B. (ed. by), *Human Evolution*, Vol. 25 - n.3-4:173-185.

Gadamer, H. G. (1989), Wahrheit und Methode. Grundzüge einer philosophischen Hermeneutik, (Engl. Transl. 1960, *Truth and Method*) .

Gagliasso E. (2001), *Verso un’epistemologia del mondo vivente. Evoluzione e biodiversità tra legge e narrazione*, Guerini, Milano.

Gagliasso E. (2009), “Bauplane e vincoli di struttura: da ostacoli a strumenti”, *Logiche del Vivente, evoluzione, sviluppo, cognizione nell'epistemologia francese contemporanea -Discipline Filosofiche*, XVIII, 1.

Gagliasso E., Frezza G. (a cura di) (2010), *Metafore del Vivente. Linguaggi e sperimentazione in filosofia, biologia e scienze cognitive*, Franco Angeli, Milano.

Gallese V., Keysers C., Rizzolatti G. (2004), «A unifying view of the basis of social cognition», *Trends in Cognitive Sciences*, p. 396-403.

Gallois L. (1918),*“*Un géographe dauphinois: Oronce Fine et le Dauphiné sur sa carte de France de 1525*”, Revue de Géographie alpine*, 6-1: 1-25.

Geymonat L., “Prefazione”, in Sambursky (1956) cit.

Giannantoni G., Plebe A., Domini P. (1975), *Storia della filosofia*, 3 vol.,Vallardi, Milano.

Gibson J.J. (1979), *The ecological approach to visual perception*, Houhghton-Mifflin, Boston.

Gilbert S. (2010), *Developmental biology*. Ninth edition, Sinauer Associates, Ne York.

Girard J.-Y. (2001), “Locus Solum”, *Mathematical Structures in Computer Science*, 11:301 – 506.

Girard J.-Y. (2006) *Le point aveugle, tome 1 : vers la perfection*. Visions des Sciences. Hermann, Paris

Girard J.-Y. (2007) *Le point aveugle, tome 2*: vers l’imperfection. Visions des Sciences. Hermann, Paris.

Goethe J.W. (1989), *Goethe’s botanical writings*, Ox Bow Press, Woodbridge.

Goethe, *Versuch die Metamorphose der Pflanzen zu erklären*, 1790 (Engl. trad. Metamorphosis of Plants).

Gould S. J., Lewontin R.C. (1979), “The Spandrels of San Marco and the Panglossian Paradigm. A critique of the Adaptationist Programme”, *Proceedings of the Royal Society*, London, Series B, 205: 581-598.

Gould S.J. (1996), *Full House: The Spread of Excellence From Plato to Darwin*, Harmony Books, New York.

Gould, S.J., Vrba E.S. (1982), "Exaptation, a missing term in the science of form". *Paleobiology*, 8(1): 4-15.

Guillaume P. (1979), *La pshychologie de la forme*, Flammarion, Paris (ed. or. 1937).

Harris H. (1995), *The cells of the body: a history of somatic cells genetics*, Cold Spring Harbor laboratory Press, Plainview, NY

Hawking R., Mlodinow L. (2010), *The grand Design*, Random House, New York

Hebb D.O. (1949), *The Organization of Behavior: a neuropsychological theory*,Wiley-Interscience, New York.

Heisenberg W. (1958) *Physics and philosophy: the revolution in modern science*, Harper, New York.

Hendrikse J.L., Parsons T.E., Halligrimsson B. (2007), “Evolvability as the proper focus of evolutionary developmental biology”, *Evolution and Development*, 9:4, 393-401.

Hesse M. (1963), *Models and Analogies in Science*, Sheed and Ward, London.

Hesse M. (1992), “Science beyond realism and relativism”, in Raven D., Vucht van Tijssen L., de Wolf J. (eds.), *Cognitive relativism and social science*, University of Utrecht, Utrecht.

Hobbes T., (1904) *Leviathan*, Cambridge Univ. press, Cambridge, 1904.

Husserl E. (1913), *Ideen zu einer reinen Phänomenologie und phänomenologischen Philosophie*, in *Jahrbuch für Philosophie und Phänomenologische Forschung*, t. I, Halle, Max Niemeyer.

Husserl E. (1928), *Vorlesungen zur Phänomenologie des inneren Zeitbewußtseins*, Husserliana – Edmund Husserl, Gesammelte Werke, Vol. X, Tübingen, Max Niemeyer Verlag.

Iriki A. et al. (1996), “Coding of modified body schema during tool use by mechanique postcentral neurones”, NeuroReport, 7:25-2330.

Jablonka E., Lamb M.J. (2005), *Evolution in four dimensions: genetic, epigenetic, behavioral, and symbolic variation in the history of life,* MIT Press, Cambridge, Mass.

Jackendoff R. (1987), *Consciousness and the Computational Mind*, MIT Press, Cambridge (Mass.).

Jacob F. (1981), *Le jeu des possibles*, Fayard, Paris.

Jacob F. Monod J. (1961), “Genetic regulatory mechanisms in the synthesis of proteins". J. Mol. Biol. 3: 318–56.

James (2007) *Principles of Psychology volume 1*, Cosimo, New York [1890].

Jammer M. (1954), *Concepts of space: the history of theories of space in physics,* Harvard University Press, Cambridge.

Jammer M. (1957), *Concepts of force. A study in the foundation of dynamics*, Harvard University Press, Cambridge.

Jammer M. (1961), *Concepts of Mass in Classical and Modern Physics*. Harvard University Press, Cambridge.

Joseph H.W.B. (1984), “Knowledge and the Good in Plato’s Republic”, *Oxford Classic & Monograph*, Oxford.

Kant E. (1999), *Critique of Pure Reason*, P. Guyer, A. Wood (eds.), Cambridge University Press (ed. or. 178).

Kauffman S.A. (1993), *The origins of Order*, Oxford University Press, Oxford.

Kim J. (2006), *Philosophy of mind*, Westview Press, Cambridge.

Köhler W. (1920) *Die physischen Gestalten in Ruhe und im stationaren Zustand*

Köhler W., (1922) Gestaltprobleme und Anfänge einer Gestalttheorie, in “Jahresbericht über die gesamte Physiologie und experimentelle Pharmakologie”, München 1924, vol. III, t. I, pp. 512-539.

Köhler W. (1926) *The Mentality of Apes*, Harcourt, Brace & Company, Inc., New York. (ed. or. 1917).

Köhler W. (1938), "Some Gestalt Problems", in Ellis, Willis D., A Source Book of Gestalt Psychology, Routledge & Kegan Paul Ltd., London,

Köhler W. (1940), *Dynamics in Psychology*. New York, Liveright.

Köhler, Wolfgang. (1947) 2006. *Gestalt Psychology: An Introduction to New Concepts in Modern Psychology*. Liveright Publishing Corporation.

Köhler, Wolfgang. (1969). *The Task of Gestalt Psychology*, Princeton University Press.

Köhler, Wolfgang. (1971). *The Selected Papers of Wolfgang Kohler*. Liveright Publishing Corporation, London.

Kuhn T.S. (1962), *The Structure of Scientific Revolutions*, University of Chicago Press, Chicago.

Kupiec, J. (2009),"L'ADN, entre hazard et coinstrantes", *Pour la science* n. 385.

Lassègue J., (2000) "On My Vicious Ways. A Response to Justin Leiber", Issue 3 response, Tekhnema, 6 / Fall .

Lakatos I., Musgrave A. (eds.) (1970), *Criticism and the growth of knowledge*, Cambridge University Press, Cambridge.

Littré É. (1838), "Œuvres d'histoire naturelle de Goethe", *Revue des Deux Mondes*, T.14.

Llinas R., (2001) *I of the vortex*, MIT Press, Boston.

Longo G. (2009), "Au sujet du livre Tout et ses parties, par Jacques Ricard", Hermann, Paris.

Longo G., Frezza G. (2010), "Crossing-over sul vivente", in Gagliasso E., Frezza G. (ed. by), *Metafore del Vivente. Linguaggi e sperimentazione in filosofia, biologia e scienze cognitive*, Franco Angeli, Milano.

Longo G., Montévil M. (2011), *Protention and retention in biological systems* (submited for publication, see http://www.di.ens.fr/users/longo/).

Lorentz H.A., Einstein A., Minkowski H., Weyl H. (eds.) (1952), *The principle of relativity: a collection of original memoirs on the special and general theory of relativity,* Dover, N.Y.

Lovelock J. (1979), *Gaia. A new look at life on earth,* Oxford University Press, Oxford.

Lucretius (1916), *De Rerum Natura*, Ellery Leonard W.(ed.), E. P. Dutton, Boston.

Malcolm J. (1962), "The line and the Cave", *Phronesis*, 1: 38-43.

Maturana H., Varela F. (1980), *Autopoiesis and cognition: the realization of the living*. D. Reidel, Dordrecht.

Mazzeo M. (2003) *Tatto e linguaggio, il corpo delle parole*, Editori Riuniti, Roma.

McLaughlin B. (1992), "The Rise and Fall of British Emergentism",

Beckermann A., Flohr H., Kim J., (eds.), (1992) *Emergence or reduction? essays on the prospects of nonreductive physicalism*, De Gruyter, Berlino, New York: 49-93.

Mecacci L. (1979), *Brain and history: the relationship between neurophysiology and psychology in Soviet research*, New York, Brunner/Mazel.

Mecacci L. (1999), Psicologia moderna e post-moderna, Laterza, Bari-Roma.

Mecacci L., Zani A. (1982), *Teorie del cervello dall'Ottocento a oggi*, Loescher, Torino.

Merleau-Ponty M. (1989), *Le primat de la perception et ses consequences philosophiques*, Ed. Cynara, Grenoble.

Merleau-Ponty M. (1945), *Phenomenologie de la perception,* Gallimard, Paris.

Morin E., (1977), *La Méthode* (6 vol.), *La Nature de la nature* (t. 1), Le Seuil, Paris.

Murphy N.R. (1932), "The Simile light in Plato's republic, *Classical Quaterly XXVL.*

Nicolis G., Prigogine I. (1977), *Self –organization in nonequilibrium systems*, J. Willey, N.Y.

Nietzsche F. (2001), *The gay science*, (ed. by) Williams B., Cambridge University Press, Cambridge (ed. or. 1882).

Nurse P. (2008), "Life, logic and information" in Nature, Vol 454, pp.424-426

Oppenheimer, J. R (1954/1955), *The open mind. Science and the common understanding*, Simon and Schuster, N.Y.

Pastoureau M. (2010), *Les couleurs de nos souvenirs*, Seuil, Paris.

Pattee H.H. (2001),"The physics of symbols: bridging the epistemic cut, *Biosystems*, 60,1-3: 5-21.

Petitot J., Varela F.J., Pachoud B., Roy J.-M., (eds.) (1999), *Naturalizing phenomenology. Issues in contemporary phenomenology and cognitive sciences*, Stanford University Press, Stanford, California.

Plotnikov A., Zehorai E., Procaccia S., Seger R., (2010), "The MAPK cascades: signaling components, nuclear roles and mechanisms of nuclear translocation", Biochim. Biophys. Acta, Dec 16.

Pontalis J.-B., Laplanche J. (1998), *Fantasme originaire, fantasmes des origines, origines du fantasme*, Hachette, Paris.

Ricoeur P. (1969), *Le conflit des interprétations*, Essais d'herméneutique I, Le Seuil, Paris.

Rizzolatti G., Craighero L. (2004), "The mirror neuron system", *Annual Review of Neuroscience*, 27: 169-92.

Rizzolatti G., Sinigaglia C. (2006), *So quel che fai. Il cervello che agisce e i neuroni specchio*, Cortina, Milano.

Rosenberg A. (2001), "How is Biological explanation possible?", *British Journal for the Philosophy of Science,* 52 (4): 735-760.

Rosenberg A. (2009), "Why do Temporary Invariances Explain in Biology and the Social Sciences?" www.duke.edu/~alexrose/InvariancesBioSocSci.pdf

Rosenthal V., Visetti Y.-M. (1999), "Sens et temps de la Gestalt", *Intellectica*, 1, 28: 147-227.

Ross, D. W. (1951) Plato Theory's of Idea, Clarendon Press, London.

Rossi P. (1971), "Sul declino dell'astrologia agli inizi dell'età moderna", in Id. *Aspetti della rivoluzione scientifica*, Morano, Napoli.

Russo L. (1997), *La rivoluzione dimenticata: il pensiero scientifico greco e la scienza moderna*, Feltrinelli, Milano.

Sambursky S. (1956), *The physical world of the Greeks*, Routledge and K. Paul, London.

Schneider S.H., Boston P.J. (1991), *Scientist of Gaia*, MIT Press, Cambridge.

Schrodinger, E. (1996) *Nature and the Greeks and Science and*

Humanism, Cambridge University Press , Cambridge.

Schuhl, P.-M., (1952) "Les premieres etapes de la philosophie biologique:", *Revue d'histoire des sciences et de leur applications*, 5, 3, pp. 197-221.

Segal G. (1996), "The modularity of theory of mind", p. 141-157, in Carruthers P., Smith P.-K., *Theories of theory of mind*, Cambridge University Press.

Shipley T. (ed) (1961) *Classics in Psychology*, Philosophical Library, New York

Simplicius (De Caelo), *On Aristotle On the heavens* 2.1-9, (2004) Müller I. (trans.), Cornell University Press and Duckworth, London, Ithaca, NY.

Smith B. (ed. by) (1988), *Foundations of Gestalt Theory*, Philosophia, Munich.

Sontag S. (1990), *Illness as a metaphor and AIDS and its metaphors*, Doubleday, New York (ed. or. 1977).

Spemann H. (1938) *Embryonic development and induction*, Yale Univ. Press, New Haven.

Suarez M., Dorato M., Redei M. (eds.) (2010), *EPSA, Epistemology and methodology of science. Launch of the European Philosophy of science association*, Springer, Dordrecht, Heidelberg, London, New York.

Tauber A. I. (1994), "Nietzsche's biology", *Biology and Philosophy*, 9:25-44.

Tauber A.I. (2009), *Science and the quest for meaning*, Baylor Univ. Press, Waco, Texas.

Thomas K., (1983), *Man and the natural world. A history of the modern sensibility*, Pantheon books, New York.

Thorndike L. (1955), "The true place of astrology in the history of science", *Isis*, 46.

van der Veldt (1928), *L'apprentissage du mouvement et l'automatisme*, Vrin, Paris.

Varela, F.J. (1979), *Principles of Biological Autonomy*, Elsevier, New York, North Holland.

Vuillemin J., (1984) *Necessité ou contingence. L'aporie de Diodore et les systèmes philosophiques*, Minuit, Paris.

Vygotsky L. S. (1999), *The collected works*, Vol. 6 Scientific legacy, Kluwer, New York.

Waddington C. H. (1975), *The evolution of an evolutionist*, Edinburgh University Press, Edinburgh

Weiss P., Kavanau J.L. (1957), “A model of growth control in mathematical terms”, J. Gen. Physiol., 41: 1-47.

Wertheimer, (1912b) “Experiments on the perception of motion”, Extraits in Shipley (1961) cit. , :1032-1089

Wertsch J.V. (1998), Mind as action, Oxford University Press, New York.

West G.B., Brown J.H, Enquist B.J. (1997), “A general model for the origin of allometric scaling laws in biology”, *Science*, 276:122-126.

Whitehead A. N. (1920), *The concept of nature*, Cambridge Univ. Press, Cambridge.

Wittgenstein L. (1953), Philosophical Investigations, Basil Blackwell , Oxford.

Witzany G. (1995), “From the logic of the molecular syntax to molecular pragmatism”, *Evolution and cognition*, 1(2): 148-168, Vienna University Press.

Witzany G. (2005), “Natural History of life: history of communication logics and dynamics”, *SEED* (1): 27-55.

Witzany G. (2006), “From Umwelt to Mitwelt, natural laws versus rule-governed sign-mediated interactions”, *Semiotica*, 1/4: 1-14.

Wolpert L. (1993), *The Unnatural Nature of Science*, Harvard University Press, Cambridge.

Wundt W. (1896), *Grundriss der Psychologie*, Engelmann, Leipzig.