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Some Lessons of Quantum Mechanics for Cognitive Science: Intentionality and Representation

Abstract: The quantum-mechanical measurement problem is briefly discussed and the philosophical lessons are drawn. In particular, the relevant role of dynamics is pointed out and this is presented as a trade-off between determination and correlation. Then it is shown that also the mind should be understood as a dynamical relationship between active reference and representation. A new understanding of intentionality is finally proposed.

Key words: dynamic trade-off, correlation – determination, reference – representation, operational intentionality – representational intentionality.

Résumé : **Quelques leçons tirées de la mécanique quantique à l'usage des sciences cognitives : intentionnalité et représentation.** Tirant la leçon philosophique d'une brève discussion du problème quantique de la mesure, on met en avant le caractère dynamique de la transaction entre détermination et corrélation. De là, on montre qu'une compréhension de l'esprit humain comme étant l'expression d'une relation dynamique entre référence active et représentation nous amènerait à une nouvelle conception de l'intentionnalité.

Mots-clés : transaction dynamique, corrélation – détermination, référence – représentation, intentionnalité opératoire – intentionnalité représentationnelle.

QUANTUM MECHANICS

In classical physics, the evolution of a physical system, let us say a one-dimensional particle, can be represented by a curve in the phase space - whose axes are position and momentum (i.e. mass times velocity) - that consists of the ensemble of the points each one standing for a perfectly (in terms of space, time and velocity) determined system's state.

In quantum mechanics, due to the uncertainty principle, instead of a line we have a worm composed of spots: In fact, any improvement in the knowledge of momentum, for instance, will be paid in terms of a proportional increase of uncertainty for position and *vice versa*.

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The uncertainty principle is a consequence of the fact that quantum observables do not generally commute, i.e. the product between momentum and position is not equal to the product between position and momentum. (The physical quantities, such as energy, speed, and so on, in classical mechanics are continuous and are therefore mathematically described by variables and functions of variables, whereas in quantum mechanics they are described by operators and are called *observables*.)

As a consequence of the uncertainty principle, the principle of perfect determination, which characterizes not only classical mechanics, but all classical way of thinking, is no longer valid in quantum mechanics. This principle, also known as *omnimoda determinatio*[1], states that between every possible predicate of an object and its negation, one of the pair must be actualised.

However, this feature alone is not sufficient to explain the novelty of quantum mechanics. This novelty clearly appears when we move on to consider the measurement process in the frame of a theory that is founded on the *superposition principle*. In fact, since in classical mechanics the physical systems are already perfectly determined, measuring means a registration of a datum and, therefore, there is (in principle) a perfect isomorphism between a measurement's result and the value of the physical quantity measured on the state the system is in, independently from the measurement and before measuring. It is only a technological problem to find the appropriate instruments for approaching this ideal situation. To this type of theory, an epistemology of representation (following which a theory mirrors some data) is completely appropriate.

In the quantum-mechanical measurement process, there is no such isomorphism. In fact, if the state before measuring is a superposition relative to the measured observable, by performing a measurement a component of this superposition will be chosen (in order to obtain a determined value). For instance, if a quantum system can take a path A or a path B to reach a screen S, it will take both jointly (it will "superpose", i.e. sum both possibilities), and these two possibilities are the components of the superposition. However, when measuring, we expect to find a definite outcome. In other words, we expect the system to be *either* in path A *or* in path B, otherwise one could not speak of a measurement.

Most importantly, in quantum mechanics, before measuring, one cannot foresee with certainty what this component will be: One can only write some probability distribution for the different results (by using what is known as the statistical algorithm). On the contrary to what happens in a classical frame, in quantum mechanics probability is irreducible. This can be very well seen in the case of radioactive decay. We can say that the radioactivity of a given material will be

[1] Baumgarten, 1739, § 148; Kant, 1763, p. 76; Kant, 1787, pp. 599-602.

reduced to half in a given time interval. However, it is not possible to predict which atom will decay at which time, even though all the atoms can be thought of as being in the same state. In other words, there is no experiment that can be performed in order to predict with certainty which atom will decay next and at what time. We can only speak of a certain probability that a particular atom will decay in a given time interval.

This situation, which is absurd from the point of view of classically-minded physicists, has induced speculations about how measurement in quantum mechanics can work: Someone has attributed to the mind the power of intervening in a physical process such that the observation could obtain the desired result, i.e. the determination that fails in the initial superposition (supposing that the system is initially in superposition relative to the measured observable). In fact, von Neumann says:

> "the measurement or the related process of the subjective perception is a new entity relative to the physical environment and is not reducible to the latter. Indeed, subjective perception leads us to the intellectual inner life of the individual, which is extra-observational by its very nature"[2].

It seems rather strange that a physical measurement is here compared to a subjective perception that von Neumann conceived as an extra-observational phenomenon. Others have theorized that no reduction to a component of a superposition happens but that our universe is only one among infinite others existing on the same footing, every one realising a component of the superposition, the so-called many-world interpretation[3].

Actually, measurement can be explained by using the formalism of quantum mechanics itself, thanks to decoherence[4]. It is sufficient that at least two physical systems which are open to environment interact in order to obtain the required determination. In fact, one can download in the environment the interference terms that are due to the superposition. By downloading the useless information in the environment (interference is a kind of "disturbance") and making possible the acquisition of useful information (the information, for instance, about the path taken by the observed system), one actually chooses to black out part of the initial information: This operation is irreversible.

Moreover, when three systems interact (object system, apparatus and environment), we can overcome a problem that affects all traditional explanations of measurement in quantum mechanics: the

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[2] Von Neumann, 1955, p. 418.
[3] Everett, 1957; Dewitt, 1970.
[4] Zurek, 1981, 1982; Cini, 1983.

basis degeneracy. In fact, a single quantum system or a pair of interacting quantum systems (for example, object system + apparatus) can be decomposed in different bases, i.e. their state can be "considered" relative to many observables, so that, if only the object system and apparatus are considered, then it seems that the apparatus contains information not only about the observable that is actually measured, but also about many others though these generally do not commute with the former. This is impossible because non-commuting observables are mutually exclusive and cannot be jointly measured. Though biorthogonal decomposition is not unique, triorthogonal decomposition (when three systems are considered) is, i.e. a given state can be decomposed relative to one observable alone: This is a clear advantage of decoherence which introduces environment as an explicative tool and not as an *ad hoc* hypothesis.

The most important point is that decoherence is a tool for interpreting measurement as a particular case of the class of dynamical processes. In fact, spontaneous "measurements" are also thought to exist in nature: It suffices that at least two systems which are open to the environment interact so that determination relative to an observable may be spontaneously obtained.

THE LESSONS OF QUANTUM MECHANICS.

The previous approach forces us to rethink about ontology[5]. As we have said, according to classical mechanics any system is already completely determined in itself. It needs no relationship to another reality in order to be as it is. Its properties are intrinsic. For this reason, dynamics is an external event to the nature of the system, which is therefore only "displaced" in different physical situations. In fact, classically, when several systems interact, the resulting total system can be considered as a mere product of the components, i.e. most relevant physical quantities are added by vectorial or scalar sum and the total state can be factorised in component states. As we shall see, in quantum mechanics factorisation is in general not possible and dynamics (the interaction with other systems) is so important that the system can acquire properties that it did not have before. Therefore, properties are relational and dynamical here. In order to understand this point more clearly, let us analyse the elements of the measurement process.

The first aspect is the discontinuous *emergence of an event*. As we have stressed above, in quantum mechanics one cannot foresee the value that an observable will have if measured. Moreover, while in classical mechanics successive measurements of the same variable may increase the degree of determination of the value it has and successive measurements of conjugate pairs (such as position and momentum) will determine the state of the system (almost) perfectly,

[5] Auletta, 2000, pp. 263-428, 513-26, 795-800.

in quantum mechanics any measurement will in general disturb the state of the system and therefore produce a new situation[6]. In other words, a series of measurements in general cannot increase the information about a single system one can acquire by a single measurement[7]. Therefore, we are forced to admit that in quantum mechanics the emergence of an event is an irreducible reality, and this is strictly related to the decision problem. In fact, we choose to measure a given observable or another and every time the effects on the system and the acquired knowledge will be different and to a certain extent incompatible.

Another component of this theory is *relationality*, which represents the continuous aspect here. In fact, all quantum correlations (the interdependencies that exist among different subsystems), differently from what happens for the classical ones, are typically a negation of the separability of correlated subsystems, i.e. of the factorisability of their states. In other words, they constitute a whole that is deprived of the discontinuities represented in some cases by distinct and wholly determined spatial localisations or, in general, by wholly determined and independent values of physical quantities belonging to the different subsystems. Another way to see the problem is to consider that a superposition or an entanglement - when more (correlated) systems are considered (however, there are important differences between these two concepts) - comprehends all possible ways to put together some alternatives, and this is clearly another form of continuity and of undecidibility of a concrete and discrete actualisation. For instance, in the bidimensional state $|\psi> = \cos \theta |0> + \sin \theta |1>$ (and, apart from a relative phase factor, any bidimensional state can be written so), θ assumes all possible values between 0 and 2π and multiples.

I wish to stress that we cannot detect directly the "superposed" reality – this would mean that we could measure the state of a quantum system with a single measurement act[8] - but only infer it indirectly. This is precisely because any measurement is local in nature. We should here carefully distinguish between two features. One thing is the reason of the quantum (detection) event: There are no reasons why we obtain this result and not another. Another thing is if this result comes from nothing. This is impossible (nothing comes out from nothing). Then, there must be a form of reality that somehow establishes the general (but not the particular) conditions from which the event comes out, and this is represented by quantum correlations.

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[6] Bohr, 1928.
[7] D'Ariano/Yuen, 1996.
[8] See D'Ariano/Yuen, 1996.

When we consider the problem on a cosmological plane, we see that, if the universe were a unique wave function representing a universal superposition without subsystems, we would never have a choice of a specific component, neither at the global level, nor at a particular level. It would be such an ordered universe that it could not present any of the typical asymmetries, fractures and singularities which characterise the events of our world and which represent that discontinuous aspect of life that we experience every day. It would be a zero-entropy universe, i.e. a universe without disorder (any so-called pure state is a zero-entropy state).

Finally, *dynamics* is a mediation process between mutually exclusive realities: Correlations are the negation of individuality and vice versa: a wholly correlated world would be a world without events, whereas a world without correlations would be a world pulverised in space-temporal atoms, not differently from what was already thought by the Islamic sect of the *qalam*.

I have said that measurement can be conceived of as a special case of dynamic interaction. In fact, dynamics can be understood in general terms as a trade-off between correlation and determination, and, in particular, I wish to point out that it is sufficient that two or more systems that are open to the environment interact in order to establish the necessary condition to obtain a determined result. It is as if physical systems (due to their openness to the environment) would continually measure each other. The fact that dynamics is a trade-off between correlation and determination is clear when one considers that the result of a measurement can never be completely determined but there is always some degree of fuzziness and indetermination (the useless information will never be completely downloaded in the environment).

We can finally draw some general conclusions. 1. We are obliged to assume an operational point of view: An *ens* (a system) and its properties are a consequence of an operation (an interaction) that we choose to perform on it. 2. To this subjective operationalism an objective one (dynamism) corresponds: We do not have static and fixed beings, but events as results of processes, and the "main" reality is constituted by processes. Let us develop the last point a little more. Since dynamics is a trade-off between correlation and determination, it is dynamics that allows determination if any. In other words, properties and systems are consequences of dynamics, and these consequences may be changed in a further dynamical development. For this reason, they are events and not substantial realities with a being fixed once and for all. 3. From the two conclusions above, we can say that the traditionally philosophical distinction between subjective and objective domain fails. This distinction supposes a pre-given and fixed world that is somehow reflected by a detached and separated subject. In my view, the subjective sphere is strictly interwoven with the "world" and vice

versa. They are structurally similar and only the interactions between these two domains are of importance.

COGNITIVE SCIENCES

How can we apply these results of quantum mechanics to other domains and in particular to cognitive sciences? I am here in particular interested to question of representation and intentional acts. It is clear that we cannot immediately apply specific tools of quantum mechanics to cognitive sciences, such as the superposition and the uncertainty principles, though there are some attempts in this direction[9]. However, its philosophical lessons are interesting from different points of view.

First, there are a lot of "negative" lessons. We do not need to apply to cognitive sciences traditional views such as the idolatry of facts, the idea that the subject is passive and that knowledge is a registration of data, the reductionist methodology. Such views were generally justified by invoking the Authority of physics.

Second, it is clear today that the mind is a dynamical entity. The mind's scope and function is not to statically mirror the surrounding world, but to act, to choose, to prevent, to anticipate, to build interpretations and models. In particular, the mind displays an activity where cognition and environment are simultaneously enacted. I shall return to this latter point at the end of this paper.

Let us consider two examples of the mind's dynamism: Vision and linguistic competences. There are at least two systems of vision[10], one for execution and individuation of movements, the other for representing. From the quoted investigations it is evident that, if I need to anticipate movements or to correct them when the target rapidly changes position or trajectory, as is the case in many sports, I have no time for representing (one may think about Formula 1 drivers). In many sports we have only the time to perceive a moving shadow: It is only the context and the direction of the moving shadow that assures us that it is a ball or a car or whatever it can be. In other words, the perception and execution of motion do not rely in general on shape perception and object recognition. Saccadic eye movements are typically completed while the hand is still moving to grasp an object. When a second saccade (correction saccade) follows, the action can be corrected when the object is displaced (up to a certain range). No additional time is required on displaced-target trials. Then, the subject can correctly grasp the displaced object though perceptually the subject is at no time able to realize that the object jumped to the new location. If the subject tries to deliberately follow the trajectory of a displaced object, the

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[9] Penrose, 1994.

[10] Paillard, 1987; Milner/Goodale, 1995; Milner, 1999; Berthoz, 2000.

movements are slower and fall well outside the amplitude-duration curve. In other words, adjustments in the trajectory are fine-tuning of the visuomotor system independently of perception. Visual (apperceptive) agnosia[11] provides further evidence of this: Patients can post a letter though they have no perception of shapes (they cannot describe them). More recent experiments show that, while there are patients affected by visual agnosia with an inability to perceive or discriminate shape and size of objects but who can successfully perform visuomotor tasks[12], there are also patients affected by optic ataxia who are disturbed in their visuomotor system and therefore show a deficit in real grasping, though they show good grip scaling when "pantomiming" (a form of representation in the literal sense of the word) a grasp for an object seen earlier and no longer present[13]. The opposite impairment is when a patient may perform quite normally some performance tasks but cannot imitate the same movement for the sake of re-presenting[14].

Actually, there are two pathways of visual information: The dorsal pathway, which is mainly concerned with movement-processing and the ventral pathway, which is concerned with colour- and form-processing. Ventral pathway has to do with the question "what is it?" whereas dorsal pathway with the question "where is it?" The dorsal system is not deceived by optical illusions. Vision for action is viewpoint-dependent, uses short-lasting representation, and it is a guide for interacting with objects, while vision for perception is viewpoint-independent and uses long-lasting representation.

Another evidence is represented by the fact that there are some patients that are impaired in recognizing living things and others that are impaired in recognizing non-living things. This can be explained by a model[15] which presupposes a distinction between visual units and functional units. While the visual units process information about the visual characteristics of objects (shape, colour, and so on), the functional units possess semantic information about the use of objects or about appropriate ways of interacting with them. It is obvious that we interact with, and use more frequently non-living objects. This model is surely an oversimplification, but more recent models[16], while stressing interactive processes, have essentially confirmed this basic distinction.

In conclusion, one must be able to refer oneself to objects and perceptual stimuli beyond and independently of the representation that would be normally evoked by these objects and stimuli. It is in

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[11] Farah, 1990.
[12] Milner, 1997.
[13] Milner *et al*., 2001.
[14] Merleau-Ponty, 1945, pp. 119-22.
[15] Farah/McClelland, 1991.
[16] Humphreys *et al.,* 1995; Humphreys/Forde, 2001.

particular the work of Gibson[17] that has pointed out, in opposition to the old, representational school of vision, that vision has to be studied as a process of active interaction with an environment.

In the case of language, it has been shown by Saul Kripke[18] that proper names express a pure reference without interpretation[19]: A proper name is not a shortcoming of a definition, as Frege thought[20]. It is my ability to refer myself to objects and events beyond and independently from an interpretation that allows the correction of a wrong interpretation. In fact, when an interpretation of an event does no longer work, not work any more, when there is something that does not fit, when I am hurt by something that, unresolved in my mental schemes, is a challenge and a problem for me - and for pragmatism, knowledge begins by problems and is, in general, a problem-solving
enterprise[21] -, then I am forced to acknowledge that my interpretation of the thing X is not a good one, and this X is my referent.

An interesting example, that connects visual and language features, has been studied by De Haan *et al.*[22]: A patient is able to match faces and names of famous people without recalling autobiographical information.

The analysis of Kripke has been anticipated by Peirce to a certain extent, but in more general terms since he takes the problem of signs into account, i.e. on a semiotic plane rather than on a linguistic one. Peirce says[23] that

> "a sign stands for something to the idea which it produces, or modifies. Or, it is a vehicle conveying into the mind something from without. That for which it stands is called its object; that which it conveys, its meaning; and the idea to which it gives rise, its interpretant. The object of representation can be nothing but a representation of which the first representation is the interpretant. But an endless series of representations, each representing the one behind it, may be conceived to have an absolute object at its limit. The meaning of a representation can be nothing but a representation. In fact, it is nothing but the representation itself conceived as

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[17] Gibson, 1950; 1966.
[18] Kripke, 1972.
[19] See also Peirce, 1867, p. 49.
[20] Frege, 1892.
[21] Peirce, 1877.
[22] (1991).
[23] CP, 1.339.

> stripped of irrelevant clothing. But this clothing never can be completely stripped off; it is only changed for something more diaphanous. So there is an infinite regression here. Finally, the interpretant is nothing but another representation to which the torch of truth is handed along; and as representation, it has its interpretant again".

The object is the referent here. The endless chain of representations can never completely exhaust the referent: At most it can ideally converge to the same referent[24]. This chain can only be broken by fixing the referent. For example, if I am studying wild ducks, it may often happen that I cannot recognize individual exemplars (i.e. my interpretation is often wrong so that I cannot rely on it). Then, I can put a ring around a duck's leg in order to acknowledge this individual. What I am doing is to fix a reference (by means of an arbitrary sign) and this without using an interpretation at all or even against a (wrong) interpretation. It is not difficult to see in this theory of reference a reformulation of the Middle Age theory of *suppositio*[25].

If our mind were only a collection of representations without referring acts, it would be like a screen, where different images come and go without any relationship among them. Hume says[26]:

> "The mind is a kind of theatre, where several perceptions successively make their appearance; pass, re-pass, glide away, and mingle in an infinite variety of postures and situations. […] The comparison of the theatre must not mislead us. They are the successive perceptions only, that constitute the mind; nor have we the most distant notion of the place, where these scenes are represented, or of the materials, of which it is compos'd".

The point is: If it is like this, I could never understand that two or more images are related to the same referent and therefore, as I have already pointed out, I could never correct my error. In my opinion, intelligence is fundamentally the ability to construct new interpretations by associating new representations or new schemes to an old referent or to apply old schemes to different and new referents – Peirce defines[27] a symbol as a declaration that a set of objects, which is referred to by a set of indices, is represented by an icon (an image, in the most simple case) associated with it. Llinàs[28] says that

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[24] See also Dewey, 1929, p. 320.
[25] Ockham SL.
[26] Hume, 1739-40, p. 253.
[27] Pierce, 1895, pp. 17 and 19.
[28] Llinàs, 2001, p. 21.

intelligence is the use of at least a rudimentary strategy. A pantomiming or theatrical being could never survive in a real world. In other words, what fails in Hume's analysis is the act of reference by which the mind is something different from a passive screen. This is a very common error in modern philosophy, and, as we have seen, it dominated the research on the brain and perception up to the 1960s-1970s.

If we try to philosophically generalize, we could say that the mind consists of two opposite realities: Representations and acts of reference[29]. The interpretation is the dynamical joint between these two extremes. *Representation* is the casting of something in the existing categorial frame and fabric of the mind, i.e. in the schemes that we use for settling objects and events. Any new experience, in fact, is absorbed in, and adapted to old experiences (and till we do not succeed, we have a feeling of uneasiness). Learning also essentially consists of framing new things in old conceptual containers. Mental elasticity essentially consists of having many and alternative containers of possible experiences. Therefore, representation is the relational aspect of mind, the continuity with the previous mental *Erlebnis*.

Representation has a dialectic relationship (through interpretation) to *referentiality*. When will the act of reference manifest itself? As I have pointed out, when the interpretation I give of an event does not work, when there is something that does not fit. Here the fundamental *intentionality* of the mind comes out, the act by which a reference can be fixed or by which the mind can refer itself to things. In fact, if the representational component of the mind can be interpreted as passive (and this is to a certain extent not so, because representation is also selective and productive), this is surely not the case for my faculty of referring to things. Whereas representation can be conceived of as a process directed from the object (but in reality: from a peripheral signal) to the mind, intentionality consists of a movement from the mind to the object. We do this every time we consciously perceive, but it is far more evident when a wrong interpretation forces us to focalise our attention on a problem, on something that we feel to be problematic. Therefore, intentionality is strictly associated to focal-attentive processing and to attention in general[30]. What imposes itself on us is often a sudden and unexpected, abrupt event[31]. In brief, a singularity that disturbs the pattern we perceive. In other occasion, often after an event has disturbed our perceptive pattern, we consciously direct our attention

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[29] See also Llinàs, 2001, pp. 12-13.

[30] See Baars, 1997a-b; Llinàs, 2001, p. 168; Husserl, 1900, II.1 V, § 19; Peirce, 1896, 3.434-35.

[31] Peirce, 1903, pp. 154-55.

to the event or object[32]: The distinction between this two forms of attention may be drawn in terms of passive and active attention[33]. A recent evidence of the continuity of the representational aspect and of the punctuality of the act of reference is that, while the sensorimotor system operates on a very short time scale, the representational system appears to take over at delays of more than a second or two[34]. Since intentionality is associated to attention, it is also interesting to consider that there can be modulation or selection of information in the auditory cortex before the sensory analysis is accomplished and therefore before a representation is formed[35]. Recent studies, in particular Llinàs contribution (2001), stress that the whole mental and cerebral activity cannot be understood without having recourse to intentionality.

Thus, I propose a concept of intentionality that is not classic, where I understand with the *classical conception of intentionality* the idea that it is a representational feature, i.e. that it refers to the contents of a representation. The concept of intentionality was introduced in modern philosophy with its classical meaning by Brentano[36], but it was already known and studied in the Middle Age – for instance, by Auriol[37]. This interpretation of intentionality was further developed by Husserl[38], though it seems that Husserl understood the relationship between reference and representation in more dynamical terms than Brentano, to the extent that, according to Husserl, the interpretation of bodies in space as continuous and smooth surfaces is formed by a process of dynamic integration of fragmented representations, any one of which is associated with a single way of obtaining kinaesthetic access to the target[39]. In other words, if I understood rightly, with a single act of reference. An almost recent authoritative supporter of the classical interpretation is Jackendoff who says[40] that people have things to talk about only by virtue of having mentally represented them. A contemporary supporter of the classical interpretation of intentionality is Searle. In his opinion[41], intentional states, as speech acts, have conditions of satisfaction. Every intentional state consists of a representative content in a certain psychological mode. A specification of the content of intentionality is already a specification of the conditions of satisfaction. It is evident that for Searle intentional acts (1) have

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[32] Peirce,1888, p. 212; see also Gemelli, 1925.
[33] James, 1890, I, p. 416-24.
[34] Rossetti, 1998; Milner, 1999.
[35] Woldorff *et al.,* 1993.
[36] Brentano, 1874.
[37] Vanni Rovighi, 1960.
[38] Husserl, 1900, 1913.
[39] Petit, 1999.
[40] Jackendoff, 1987, p. 127.
[41] Searle, 1983.

contents, (2) can be true or false, and (3) are for this reason essentially about the real world. In my opinion, none of these characters is typical of intentionality. I have already discussed the first point. As regards the second and the third ones, it seems to me that one cannot speak of truth-values for intentional acts because, among other considerations, they can refer to *everything*, imagined or experienced, concrete or abstract, possible or impossible. Nobody can hinder a person from writing an article or speaking about Mickey-Mouse or the squared circle[42]. It is only the associated interpretation or representation that can be plus or minus adequate to our reference (when, for example someone thinks that Mickey-Mouse is the mouse that yesterday ate some cheese in the kitchen). On the other hand, Searle, even if he is a supporter of the classical interpretation, has the historical merit to have pointed out the role of intentionality for the philosophy of the mind in years that were dominated by computationalism[43].

Summing up, I suggest an active and non-interpretative understanding of intentionality, i.e. an intentionality deprived as such of representational contents, even if normally associated to a representation and by means of this latter also to the contents themselves. In Peirce's terminology, intentionality is *indexical*, i.e. it is as an index pointed toward a certain direction – whereas representation is *iconic*[44]. Following again Peirce[45], we can speak of the referent to which an intentional act point as a *haecceity*, a pure thisness, i.e. a thing without qualities or properties.

Evidence for the representational emptiness of intentionality, can be found in the history of scientific discoveries. A long time before there was a clear understanding of how an atom is built, this term was already used (for the first time by Dalton) in the scientific literature in the XIX century to refer to a hypothetic entity (still in 1897 Ernst Mach was persuaded that they did not exist at all), which was able to explain the transformations of elements and the element table. Obviously, there were a lot of false representations associated with this name - first of all the idea that it was indivisible. However, the relevant point here is that one searched for a reality called *atom* whose function was to fill an explicative gap and whose nature was not known. When, at the beginning of the XX century, a cloud of negatively charged particles was found to be surrounding a positively charged nucleus, terms such as *electron* and *proton* were used though there was no clear model of the atom and no theory able to explain the behaviour of these particles (quantum mechanics was born much

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[42] See also Husserl, 1900, II.1, V § 20, *Beilage*.
[43] Searle, 1980, 1992.
[44] Peirce CP, 2.92.
[45] Peirce, 1896, 3.434.

later, in 1925). This is the very essence of the act of discovering, the fact that the scientist individuates a reality whose nature he does not understand well and can perhaps go against his own representations and cognitions. Schrödinger found the term and the concept of entanglement in quantum mechanics but this was in open conflict with his idea of how the world is or should be[46]. Another example is the discovering of Neptune. Le Verrier knew that there was something disturbing Uranus's orbit and he began to calculate the position. Successively, Galle found Neptune in the place indicated by Le Verrier. It is evident that neither Le Verrier before calculating, nor Galle before observing, knew very much about it, though the former could refer to a planet (but it could have also been a black hole, for instance) and the latter to a planet perhaps in a certain location. Intentionality can be a thread, an instrument in order to catch a reality, whose existence one supposes through interaction with other realities (and there are things, let us say quarks and photons, that are never directly experienced but known only through interaction with other things). The successive interaction with this reality (by measuring) and further inferences, calculations following these new experiences, can finally provide an *échantillon* of interpretation.

However, one could say that, in order to have a referent and therefore to exercise the intentional act, one needs a previous representation of this referent, so that it seems here that there is a regressive, endless chain. In general it is not so. In fact, the individuation of objects, properties and events appears to vary according to the task at hand[47]. Then, to individuate a referent is in principle a practical matter: One performs an action and this action has a consequence. The feedback (on the sensorimotor system) that derives from this consequence enables one to individuate a referent. It is clear that our referents of every-day life are so charged with interpretations and representations that it seems impossible to refer without somehow representing. However, the preceding examples show that this is not the right perception. For this reason, scientific discovery is a very good tool for approaching the intentional acts in their purity because, in science, very often we face situations here in which our categories reveal themselves to be inadequate.

Therefore, intentionality is strictly related to proprioceptive feedback (the mind takes a copy of a motor command as input and yields a signal identical in the form to one returning from the sensory peripheries as output). Proprioception is the inner sense that tells you how your body (or a part) is located in space[48]. In general, intentionality is strictly dependent on the relationship between movements and acts of the subject and movements and variations in

[46] Schrödinger, 1935.
[47] Brooks, 1990; Varela, *et al.,* 1991, p. 148.
[48] Clark, 1997, pp. 21-24; Varela, *et al.*, 1991, pp. 173-76.

the environment. Recently, in this context, the centrality of an organism's balance has been stressed[49]. This is not to say that representation does not have a "subjective" component: The latter element is evidently represented by the categorial frame in which the perceptual stimulus is translated and transformed. Only the relationship between this "subjective" aspect and the "objective" one (the things or events to which representation and intentionality are related) is very different when representing and when referring. (It is also evident that we can understand *perception* in two ways: Either as the whole, for example vision, which comprehends both representional system and sensorimotor system, or as the representational system alone.)

Further evidence of this state of affairs can be found in speech production[50]. The motor control systems in speech are articulated through three feedbacks: (1) An internal feedback, which consists in a feedback between the motor commands and the *intention* to speak a particular utterance and in a feedback between the motor commands and the stored spatial-temporal *speech patterns* (both through the central nervous system); (2) a response feedback between motor commands and muscle activity (and here we have the *proprioceptive* feedback); and, finally, (3) an external feedback between muscle *activity* and the *results of the acts* (sound waves, articulatory contacts, and so on). Resuming, the internal feedback has to do with speech intentions and representation, the response feedback is the proprioceptive feedback, and the external feedback has to do with activity and the results of the acts.

On the other hand, the representational side of the mind, the stored patterns and the existing schemata does not need to be understood as a reproduction of the "external" world. It only needs to be (reactively) associated to the signals we receive (through biological evolution and adaptation), and in this narrow sense we can speak of a *representation* and of a translation of stimuli in our schemes[51]. For instance, suppose that I see a door (association between some visual stimuli and schemes on the basis of precedent adaptation or experience) and I wish to push it to go in (intention). I push (action) and (following the action) I experience that the door is (unexpected) hard (new stimuli, feedback, proprioception). This causes an active redirection of intentionality in order to correct my interpretation and therefore to find new signals. I find in myself new schemes that could account for this situation (they were already associated in the past with similar stimuli). Then, a new interpretation follows almost automatically: It is a wall and the door is only painted! Finally, I search for other perceptual evidence for this

[49] Smetacek, 2002.
[50] Borden/Harris, 1984.
[51] See Llinàs, 2001, pp. 218-20.

new interpretation as well as for a possible explanation of my preceding failure (the light was too dim, I was too tired and perhaps I was deeply engaged with myself in conversation).

The problem can be thought of by analogy with the immune system. An organism produces randomly shaped antibodies: If a randomly generated antibody is the right answer to an invader, then a feedback message is immediately sent to the manufacturing plant ordering it to cease random production and to produce copies of the good biological answer[52]. Moreover, when an antibody binds somehow to an intruder, it mutates (this process is called hypermutation) in order to bind to the foreign molecule more strongly[53]. In other words, antibodies as well as representations need not be *the* optimal solutions or *the* good answer to the problems but only *an* answer that works well - also scientific explanations work like this[54] - and that, for this reason, becomes an acquired pattern that will be associated with the relative stimulus. On the other hand, feedback allows successive correction and adaptation.

AN EXAMINATION OF QUINE'S ARGUMENT ABOUT THE OPACITY OF REFERENCE

It is well known that Quine has argued[55] that reference is essentially opaque. This is a very important point for our examination. In fact, contrarily to Quine, my thesis is the univocity of referent (and of the intentional act that points to it) and we can learn very much through a critical examination of Quine's positions.

The first feature to be noted is a methodological one. Quine affirms that meaning is dependent on behaviour and dispositions to overt, public behaviour. However, there is a difference between behaviour and use of words. In fact, it is clear that for Quine the most important thing is the observation of other people's behaviour. However, language is an active cooperation in using words and in interacting through speech acts. In other words, Quine does not seem to be interested in social language (in how people use language), but in the individual *observation* of social language (in how I observe people using language). This is not a secondary point and it determines his whole argumentation.

The core of his argument about the opacity of the reference is that we cannot be sure if a word or an ostensive act refers, for instance, to a rabbit or to a part of it. My point is that we share a social and linguistic background, so that we generally know what the referents of our words are very well. In fact, it is the practical and (between speakers and between speakers and referents) interactive context to

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[52] Ford, 1989.
[53] Gearhart, 2002.
[54] Peirce, 1878.
[55] Quine, 1960, § 12; 1969, pp. 26-68.

assure the required univocity. Also in the case in which we are faced with a human of a foreign culture who is hunting a rabbit, we would very well understand the sense of this action and its referent and we would never think that this foreigner is hunting, for instance, a leg of the rabbit and not the rabbit itself. Even if the culture of this human makes use of legs for specially religious practices, we are probably legitimate in supposing that (1) in order to obtain the leg one must catch the whole rabbit, and (2) that in general one would not throw away the rest of the rabbit but eat it, so that the intention was after all to hunt a rabbit. However, suppose that we do not understand the utterance of a foreigner very well. There are two possibilities here. In the first case my misunderstanding does matter. It is then always possible to find other possible ways to help understanding. It is not only a problem of further ostension or of language. I think it is ultimately a problem of sharing a common culture and of the practical consequences of my misunderstanding. In the second case, my misunderstanding does not matter (a problem that seems to worry Quine very much in terms of an indistinguishability problem). In this case, there are no negative consequences so far, and I see no problem at all. My interpretation of the referent fits, and this is all. When this will be no longer the case, I will note it through some conflicting situation and I will correct myself later. It is also evident that according to Quine representations and interpretations are sharply defined, whereas it is most likely that they are unsharp and fuzzy[56]. Note, finally, that we also share a biological background with other animals, so that we again and very clearly understand what is the referent (the object) of a hunting animal is.

For these reasons, I think that nobody, except for a philosopher perhaps, will understand this referent, i.e. the rabbit, as "brief temporal segments of rabbit", said in Quine's words. This is in the best case a very abstract interpretation that we successively impose to a referent. Generally, to take this expression as a referent would clash with the idea (which, to a certain extent, seems to be Quine's own) that it is the use to determine the reference. And, again, I see no possible use of this expression apart from philosophical technicalities. As we shall see below, this is the central point in discussion. On the other hand, Quine's assumption here is what he calls the principle of individuation, i.e. that, if one takes the total scattered portion of the spatial-temporal world that is made up of a rabbit and that which is made up of the rabbit's parts, they are the same. The idea is the same as Locke's[57]: To be is to be in a certain place and in a certain time so that everything else must be situated in another region of space and time (or of space-time). As a consequence, everything that is in the same region is the same thing

[56] Rosch, 1973; Hampton, 1998.
[57] Locke, 1689, II.27.1.

and can be taken as a legitimate referent. I do not know where the limits of this argumentation are, if it is subjected to restriction of any type. For example, if I am in a house, am I the same thing as the portion of the house I am in? And if I am in the street? And if there are a lot of people with me? Can we all together be considered as a single referent of which we are only parts? Under certain conditions I would consider a crowd of people as a referent, but I would never consider persons as *parts* of a crowd. Moreover, if we accept Quine's explanation, we are unable to distinguish between a living rabbit with its "parts" and a detached and dead part of it (or even an assemblage of dead parts of it). However, if we are confronted with a lion and not a rabbit, our life may depend on the ability to distinguish between a live and a dead lion. For this reason, it seems extraordinary to me that a theory of reference is not able to account for such a minimal distinction given that our (of humans, but also of animals) referential (and intentional) acts are primarily concerned with the task of survival or at least with practical tasks.

And here we come to the central question. I think that the origin of all problems is that Quine does not distinguish between *to define or interpret a referent* and *to refer*: To refer is a practical matter and not a theoretical - not to speak of a philosophical - one. Instead, Quine affirms that reference is nonsense except when relative to a coordinate system, so that when we ask "Does *rabbit* really refer to rabbits?", the answer should be: "Refer to rabbit in what sense of *rabbits*?". Here the reference problem is made dependent on the sense problem - denotation on connotation. What Quine asks here is about the sense of the referent, about its interpretation. When we ask in this way, we fail to refer only because we do not understand the meaning of the word *rabbit*, so that it is a problem of the use and of the learning of the word and not at all of referring as such. A true problem of reference is the following. You say to me "Do you see that rabbit?", and I answer: "Where?". Here it is clear that I am not able to individuate the thing to which your intentional and referential act is directed and not because of a semantic misunderstanding. On the contrary, if someone says "Today I have hunted a rabbit", nobody who understands the sentence will ask "Does *rabbit* really refer to rabbits?" and surely nobody will specify "Refer to rabbit in what sense of *rabbits*?". *These* questions would be seen as nonsensical because it is clear what the referent is if the meaning of the sentence is understood[58].

It is clear that if we suppose, as I do, that our referential acts are active and by definition indeterminate and blind, we are saying that they can acquire a sense only in a given reference frame - in itself the referent remains the limits of a chain of representational and

[58] see also Chomsky, 1980, 14-22.

interpretational acts[59]. This is almost the same position as Quine's except for an important point: For Quine the referent is absorbed into the sense frame, but for me it is objectively there and reacts to our interpretation or at least to our action on it. This is evident when Quine affirms that things are indistinguishable except by their properties (the senses or connotation in which we catch the things). This is not so. First of all, I can distinguish, for instance, between two packets by marking one of the pairs with an arbitrary X, which is an exterior sign that has nothing to do with the properties of the thing. Secondly, and most importantly, to distinguish the things by their practical effects is not to distinguish them by their properties[60]. This is a major error of traditional philosophy. Suppose that I wake up in the night and in full darkness I try to go out of my bedroom. My interpretation of the relative position of the objects, the walls and door may be false so that I bang my head against the wall. This is a practical effect and I know that there is a wall in reason of the shock I have experienced. One could say that I have understood that it is a wall by the property of hardness or impenetrability. But this is only a *posterior* interpretation. The "cognitive primary event" is that I experienced a shock.

In conclusion, it seems to me that in this way some of the paradoxes proposed by Quine vanish.

FINAL CONSIDERATIONS AND CONCLUSIONS

The reversal of the traditional point of view about intentionality that I propose has far-reaching consequences. In my perspective, representational processes are the *syntactic* aspect of the mind since they essentially consists of transforming elements that are already present in the mind (perception is a signal that causes a reaction process by which we finally apply the perceptual schemes that we already have to the stimulus) following thought rules (the perceptual contents are further elaborated by these rules)[61]. These thought rules are not necessarily classically logical rules. On the contrary, it may be supposed that they are rather fuzzy logic rules[62] – it is interesting that in quantum mechanics, due to the superposition principle, we have fuzzy properties as a consequence, i.e. properties which are not completely determined (in a classical sense). Then, modern philosophers of the mind (Hobbes, Locke, Hume, etc.) essentially developed a syntactic approach.

Instead, the *semantic* aspect consists entirely of an operation (intentionality) deprived as such of representational elements and

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[59] Dewey, 1929, p. 320.
[60] Peirce CP, 6.318.
[61] Peirce, 1868.
[62] Varela *et al.*, 1991, p. 170.

whose function is to individuate referents to which a representation is associated and to which an interpretation may then be applied.

Thus, it seems to me that the mind is a dynamic process of integration of these potentially conflicting aspects: The continuous and endless chain of representations consisting in the inferences connecting them[63] and the instantaneous acts of reference. If one will, the mind and the brain are a dynamic trade off between the inherited and acquired automatisms and representations, on the one hand, and the referential acts that imply always a choice, on the other. In other words, mind is a balance between strategic, inherited or a priori schema and tactical and point-like decisions[64].

And here we return to the relationship between quantum mechanics and cognitive sciences. First, the mind is essentially a dynamic and operative device in accordance with my first conclusion about quantum mechanics, i.e. that the epistemology suggested by this theory is an operational one. However, there is also a deeper relationship. I think that quantum mechanics is the most basic theory we have of the world, although not in an old reductionist sense. It does not mean that quantum mechanics represents a frame to which all the rest should be reduced, i.e. quantum-mechanical entities are not building blocks out of which the other things are composed. The principle of superposition does not allow for such an interpretation. But quantum mechanics can throw light on some basic aspects of the world that one may suppose are at least methodologically pertinent to other domains. Furthermore, in the nature of quantum-mechanical entities there must be the *necessary conditions* that allow things like the mind, semiotic processes, intentionality, and so on. In fact, quantum mechanics can be entirely translated into informational terms, and all dynamical processes and all correlations can be seen as information exchanges and information sharing[65]. Now, the possibility to allow semiotic processes or the mind is already contained in the nature of information (I will return to this point in an another paper). The second conclusion about quantum mechanics was the primacy of dynamics and the understanding of dynamics as a mediation process between discontinuous individuality and the continuum of relationality. My hypothesis is that this is a general and basic feature that is deeply rooted in the nature of information, whose application range is very wide and which agrees very well with my analysis of the mind, where the discontinuous aspect is the intentionality and the relational one the representation. We have already stressed the strict connection of intentionality with perception and execution of movements. Then, it is not by chance that the brain

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[63] Peirce, 1868, pp. 223-24.
[64] Llinàs, 2001, p. 148.
[65] Auletta, 2000, pp. 709-781.

operates in a discontinuous manner when performing an action and when perceiving during the execution of this action[66].

Note, on the other hand, that the mind cannot be completely separated from the "material" dimension: It is a reality emerging out of biological life and in the recent literature the mind's embodiment has been pointed out[67], i.e. the fact that the mind's nature and activity cannot be separated from the body. And I have stressed that intentionality cannot be separated from the sensorimotor system. However, representation cannot be separated from the body too, due to the fact that we can "receive" information from the outside only through our senses. Therefore, one may hypothesize that the body - and life in general – presents the same essential characters the mind has in a more rudimental form. In fact, the essence of being and reacting which is common to all forms of life is the ability to move around in a dynamic environment, i.e. any living being shows intelligence[68]. Even a unicellular organism that follows some light or temperature gradient is capable of perceiving stimuli and to eventually correct a wrong interpretation of the same stimuli (for example, by changing its trajectory)[69].

Finally, I wish to stress that this is not the only hypothesis that can be formulated on the basis of the empirical evidence I have mentioned. I only hope to have convinced the reader that this is a hypothesis that is worth of further analysis and discussion.

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Bibliography

Auletta, G. (2000). Foundations and Interpretation of Quantum Mechanics. In the Light of a Critical-Historical Analysis of the Problems and of a Synthesis of the Results, Singapore, *World Scientific*, 2000; rev. ed. 2001

Baars, B. J. (1997a). Some Essential Differences between Consciousness and Attention, Perception and Memory, *Consciousness and Cognition* **6**: 363-71

- (1997b). *In the Theatre of Consciousness: The Workspace of the Mind*, Oxford, University Press

Baumgarten, A. G. (1739). *Metaphysica*, 1739; VII ed., Halle 1779; rep. Hildesheim-New York, Georg Olms, 1982.

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[66] Llinàs, 2001, p. 24-33.

[67] Varela *et al.*,1991 and Clark, 1997. See also Merleau-Ponty, 1945.

[68] Brooks, 1990; Llinàs, 2001, pp. 112-13.

[69] Griffin, 1984.

Berthoz, A. (2000). *The Brain's Sense of Movement*, Cambridge, MA, Harvard University Press (engl. tr.)
Bohr, N. (1928). The Quantum Postulate and the Recent Development of Atomic Theory, *Nature* **121**: 580—90
Borden, G. J., Harris, K. S. (1984). *Speech Science Primer: Physiology, Acoustics, and Perception of Speech*, Baltimore, Williams and Wilkins
Brentano, F. (1874). *Psychologie vom empirischen Standpunkt*, Leipzig, 1874; Leipzig, 1924; Hamburg, Meiner, 1973.
Brooks, R. A. (1990). Elephants Don't Play Chess, *Robotics and Autonomous Systems* **6** :3-15
Chomsky, N. (1980). *Rules and Representations*, New York, Columbia University Press
Cini, M., Quantum Theory of Measurement Without Wave Packet Collapse, *Nuovo Cimento* **73B** : 27—54
Clark, A. (1997). *Being There: Putting Brain, Body, and World Together Again*, Cambridge MA, MIT Press
D'Ariano, G. M., Yuen, H. P. (1996). Impossibility of Measuring the Wave Function of a Single Quantum System, *Physical Review Letters* **76**: 2832—35
De Haan, E. H. F., Young, A. W., Newcombe, F. (1991). A Dissociation Between the Sense of Familiarity and Access to Semantic Information Concering Familiar People, *European Journal of Cognitive Psychology* **3**: 51-67
Dewey, J. (1929). *Experience and Nature*, (1929); New York, Dover, (1958).
DeWitt, B. S. (1970). Quantum Mechanics and Reality, *Physics Today* **23**
Everett, H. III, (1957). "Relative State" Formulation of Quantum Mechanics, *Review of Modern Physics* **29**: 454—62
Farah, M. J. (1990). *Visual Agnosia. Disorders of Object Recognition and What they Tell us About Normal Vision*, Cambridge, MA, MIT Press, (1990, 1995).
Farah, M. J., McClelland, J. L. (1991). A Computational Model of Semantic Memory Impairement: Modality Specificity and Emergent Category Specificity, *Journal of Experimental Psychology: General* **120**: 339-57
Ford, J. (1989). What is Chaos, that we Should Be Mindful of It?, in Davies, P. C. W. (ed.), *The New Physics*, Cambridge, University Press, 1989, 1990, 1992, 1993: 348-72
Frege, G. (1892). Über Sinn und Bedeutung, *Zeitschrift für Philosophie und philosophische Kritik* **100**: 192—205; rep. in Frege, Gottlob, Begriffschrift und andere Aufsätze, Hildesheim
Gearhart, P. J. (2002). The Roots of Antibody Diversity, *Nature* **419**: 29-31
Gemelli, A. (1925). Funzioni e strutture psichiche, *Rivista di Filosofia Neoscolastica* **17**: 40-68

Gibson, J. J. (1950). *The Perception of the Visual World*, Boston, Houghton Mifflin
- (1966). *The Senses Considered as Perceptual Systems*, Boston, Houghton Mifflin
Griffin, D. R. (1984). *Animal Thinking*, Cambridge, MA, Harvard University Press
Hampton, J. A. (1998). Similarity-Based Categorisation and Fuzziness of Natural Categories, *Cognition* **65**: 137-65
Hume, D. (1739-40). *A Treatise of Human Nature*, London, 1739—40; 1888; Oxford, University Press, 1978, 1992
Humphreys, G. W., Forde, E. M. E. (2001). Hierarchies, Similarity, and Interactivity in Object Recognition: "Category—Specific" Neuropsychological Deficits, *Behavioral and Brain Sciences* **24**: 453-76
Humphreys, G. W., Lamote, C., Lloyd-Jones, T. J. (1995). An Interactive Activation Approach to Object Processing: Effects of Structural Similarity, Name Frequency and Task in Normality and Pathology, *Memory* **3**: 535-86
Husserl, E. (1900). *Logische Untersuchungen*, Tübingen, M. Niemeyer, 1900; 2nd ed. 1913, 1980, 1983
- (1913). *Ideen zu einer reinen Phänomenologie and phänomenologische Forschung*, 1913, 2nd ed. 1922; Hamburg, Meiner, 1993
Jackendoff, R. (1987). *Consciousness and the Computational Mind*, Cambridge MA, MIT Press, 1987, 1990, 1992
James, W. (1890). *The Principles of Psychology*, H. Holt, 1890; 1918; New York, Dover 1950
Kant, I. (1968). *A Kants Werke. Akademie Textausgabe*, Berlin, W. de Gruyter.
- (1763). Der einzige mögliche Beweisgrund zu einer Demonstration des Daseins Gottes; in *KANT A*: II, 63-164
- (1787). Kritik der reinen Vernunft, II ed. 1787: III v. de *KANT A*
Kripke, S. A. (1972). Naming and Necessity, in S. DAVIDSON, G. HARMAN (eds.), *Semantics of Natural Language*, Dordrecht, Reidel: 353-355; rep. Cambridge, MA, Harvard University Press, 1980
Llinàs, R. R., (2001). *I of the Vortex: From Neurons to Self*, Cambridge, MA, MIT Press, 2001, 2002
Locke, J. (1689). *An Essay Concerning Human Understanding*, 1689; 2d ed. 1694; 4th ed. 1700; Oxford, University Press, 1975, 1979, 1987, 1990
Merleau-Ponty, M. (1945). *Phénoménologie de la perception*, Paris, Gallimard, 1945, 2001
Milner, A. D. (1999). Seeing and Doing. Two Selective Processing Systems in Vision, in B. H. Challis, B. M. Velichovsky (eds.), *Stratification in Cognition and Consciousness*, Amsterdam, J. Benjamins: 13-18

Milner, A. D., Goodale, M. A. (1995). *The Visual Brain in Action*, Oxford, University Press, 1995, 1996, 2000

Milner, A. D., Dijkerman, H. C., Pisella, L., McIntosh, R. D., Tilikete, C., Vighetto, A., Rossetti, Y. (2001). Grasping the Past: Delay Can Improve Visuomotor Performance, *Current Biology* **11**: 1896-901

Ockham, W. of SL (1974). *Summa Logicæ, in Opera Philosophica*, New York, St. Bonaventure.

Paillard, J. (1987). Cognitive versus Sensorimotor Encoding of Spatial Information, in P. Ellen, C. Thinus-Blanc (eds.), Cognitive Processes and Spatial Orientation in Animal and Man. Volume II: *Neurophysiology and Developmental Aspects*, Dordrecht, Nijhoff: 43-77

Peirce, C. S. (1867). On a New List of Categories, *Proceedings of the American Academy of Arts and Sciences* **7**: 287-98; in W II, 49-59

- (1868). Some Consequences of Four Incapacities, *Journal of Speculative Philosophy* **2**: 140-57; in W II, 211-42

- (1877). The Fixation of Belief, *Popular Science Monthly* 12: 1-15; in W III, 242-57

- (1878). Deduction, Induction, and Hypothesis, *Popular Science Monthly* **13**: 470-82; in W III, 323-38

- (1888). Trichotomic, in *VI*, 211-15

- (1895). Of Reasoning in General, in *EP*: II, 11—26

- (1896). The Regenerate Logic, *The Monist* **7**: 19-40; rep. in CP: 3.425-55

- (1903). On Phenomenology, in *EP* II, 145—59

- (1958). *CP The Collected Papers*, Vols. I-VI (eds. C. Hartshorne, P. Weiss), Cambridge, MA, Harvard University Press, 1931-1935; vols. VII-VIII (ed. Arthur W. Burks), Cambridge, MA, Harvard University Press.

- (1998). *EP The Essential Peirce*, Bloomington, Indiana University Press, vols. I—II

- (1982). *W Writings*, Bloomington, Indiana University Press.

Penrose, R. (1994, 1996). *Shadows of the Mind: A Search for the Missing Science of Consciousness*, Oxford, University Press.

Petit, J.-L. (1999). Constitution by Movements: Husserl in Light of Recent Neurobiological Findings, in J. Petitot, F. J. Varela, B. Pachoud, J.-M. Roy (eds.), *Naturalizing Phenomenology: Issues in Contemporary Phenomenology and Cognitive Science*, Stanford, University Press: 220-44

Quine, Willard van Orman (1960). *Word and Object*, Cambridge, MA, MIT University Press, 1960, 1989

- (1969). *Ontological Relativity and Other Essays*, New York, Columbia University Press

Rosch, E. H. (1998). Natural Categories, *Cognitive Psychology* **4**: 328-50

Rossetti, Y. (1998). Implicit Short-Lived Motor Representations of Space in Brain Damaged and Healty Subjects, *Consciousness and Cognition* **7**: 520—58

Schrödinger, E. (1935). Die gegenwärtige Situation in der Quantenmechanick. I—III, *Naturwissenschaften* **23**: 807-12, 823-28, 844-49

Searle, J. (1980). Minds, Brains, and Pograms, *Behavorial and Brain Sciences* **3**: 417-24

- (1983). *Intentionality: An Essay in the Philosophy of Mind*, Cambridge, University Press, 1983, 1997

- (1992). *The Rediscovery of the Mind*, Cambridge Mass, MIT Press, 1992, 1994; VII print. 1998

Smetacek, V. (2002). Mind-Grasping Gravity, *Nature* **415**: 481

Vanni Rovighi, S. (1960). Una fonte remota della teoria husserliana dell'intenzionalità, in E. Paci (ed.), *Omaggio a Husserl*, Milano, Il Saggiatore

Varela, F. J., Thompson, E., Rosch, E. (1991). *The Embodied Mind: Cognitive Science and Human Experience*, Cambridge, MA, MIT Press, 1991, 1993, 2000

von Neumann, J. (1955). *Mathematical Foundations of Quantum Mechanics*, Princeton, University Press

Woldorff, M. G., Gallen, C. C., Hampson, S. A., Hillyard, S. A., Pantev, C., Sobel, D., Bloom, F. E., Modulation of Early Sensory Processing in Human Auditory Cortex During Auditory Selective Attention, *Proceedings of the National Academy of Sciences of U.S.A.* **90**: 8722-26

Zurek, W. H. (1981). Pointer Basis of Quantum Apparatus: Into What Mixture Does the Wave Packet Collapse?, *Physical Review* **D24**: 1516-25

- (1982). Environment-induced Superselection Rules, *Physical Review* **D26**: 1862-80