The New Experimental Science of Physical Cognitive Systems

AI, Robotics, Neuroscience and Cognitive Sciences under a New Name with the Old Philosophical Problems?

Fabio Bonsignorio

Abstract. It is likely that in AI, Robotics, Neuroscience and Cognitive Sciences, what we need is an integrated approach putting together concepts and methods from fields so far considered well distinct like non linear dynamics, information, computation and control theory as well as general AI, psychology, cognitive sciences in general, neurosciences and system biology. These disciplines usually share many problems, but have very different languages and experimental methodologies. It is thought that while tackling with many serious 'hard core' scientific issues it is imperative, probably a necessary (pre) requisite, that we do serious efforts to clarify and merge the underlying paradigms, the proper methodologies, the metrics and success criteria of this new branch of science. Many of these questions have already been approached by philosophy, but they acquire in this context a scientific nature: e.g.: Is it possible cognition without consciousness? And without 'sentience'? In the context of AI and neuroscience research various definition of consciousness have been proposed (for example by Tononi, [44], to quote an example liked by the author). How they relate to the previous and contemporary philosophical analysis? Sometimes scientists may look as poor philosophers, and the opposite: philosophers may look as poor scientists, yet, the critical passages of history of science during a paradigm change or the birth of a new discipline have often involved a highly critical conceptual analysis intertwined with scientific and mathematical advancements. The scientific enterprise is now somehow close to unbundle the basic foundation of our consciousness and of our apperception of reality, and, it is clear that there are some circularity issues with the possible 'explanations', at least.

Fabio Bonsignorio
University Carlos III of Madrid and Heron Robots

V.C. Müller (Ed.): Philosophy and Theory of Artificial Intelligence, SAPERE 5, pp. 133–150.
springerlink.com

1 Introduction

On the one hand AI and Robotics develop new artificial systems showing some features of what we call intelligent/cognitive adaptive behavior or intelligent thinking, on the other hand neuroscience, cognitive sciences and biology reverse-engineer intelligent/cognitive processes in natural systems. Despite 50 years of research in AI and Robotics the real capabilities of artificial systems to deal with open-ended environments with gaps of knowledge is still unsatisfactory. It is apparent that not only the more evolved human or mammalian brains, but even the 'simple' 15-20000 neurons Aplysia nervous system shows much more robust and adaptive than any current AI or robotic application. Not surprisingly while there are impressive and fast progresses in the decoding of micromechanisms of neural activation in the brain or of gene regulation networks in the cell we still lack working quantitative models of emergent system level processes like symbol grounding or multicellullar organism tissue specialization. In particular new fields of research like system biology try to fill those gaps.

One of the books defining the beginning of what we today call science had the title ‘Principia Mathematica Philosophiae Naturalis’. The revolution in physics in the early 20th century, special and general relativity and quantum mechanics, as well as the new foundation of biology in the 50s, around the ‘central dogma’, required a deep conceptual analysis whose essential nature was philosophical.

The question ‘Can a machine think?’ requires a careful definition of what you mean as a ‘machine’ and as ‘thinking’ (maybe also of what do you mean as ‘to can’).

An interesting question from the conceptual standpoint is which are the system level characteristics which allow autonomous cognitive behavior in natural systems and which set of characteristics are needed in an autonomous system in general, natural or artificial. This should be the core of the science of ‘embodied cognition’ or whatever you want to call it.

As told, we probably need a unified approach integrating together concepts and methods from research areas spanning from non-linear dynamics to information, computation and control theory, from general AI to system biology.

In the following sections a not exhaustive summary of the different positions and proposals in the different fields which should pave the way to a new unified framework, is provided, in order to make more evident the necessity of a conceptual analysis of clear philosophical nature to proceed in research in those related fields. Of course it is not possible to give a complete survey of the many activities ongoing in those research areas, the aim of this excerpt is to support the general idea of the necessity of the dialogue between those disciplines and, above all, the idea that they are aspects of a ‘deeper’ new science: the science of physical cognitive systems.

2 A Short Comparative Survey

2.1 A Short Comparative Survey of Perception and Action Modeling in AI, Robotics, Neurosciences and Cognitive Sciences

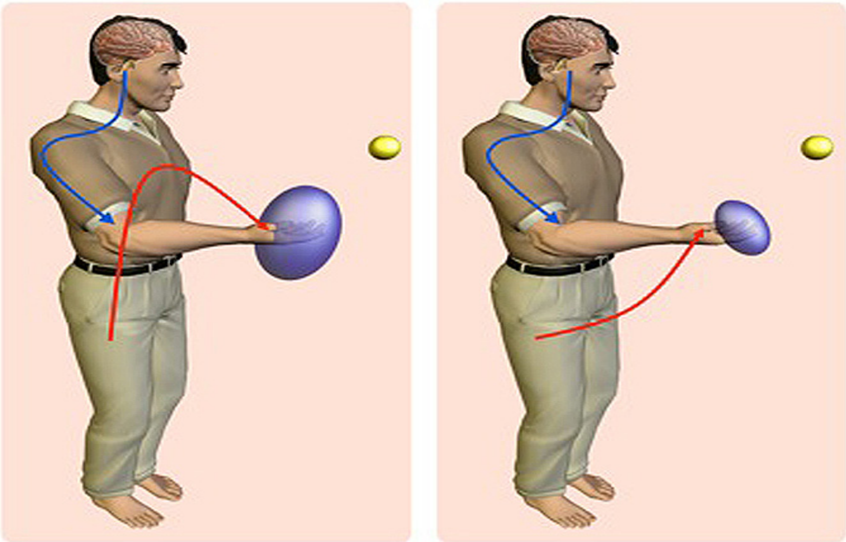

Fig. 1 ''When taking an action, such as trying to catch a ball, there are many paths the hand could take to the same final location (two possible paths are shown in red). The outgoing motor command (blue arrows) is corrupted by noise (randomness) leading to variability in the final hand position (blue ellipses) that depends on the particular path chosen. In this case it is preferable to take the path on the right, as the final variability is smaller. In general there will be one optimal path that minimizes the variability and the predictions of this model matches observed behavior.''(Courtesy: D. Wolpert)

AI, Robotics, Neuroscience and the various flavors of Cognitive Sciences all deal with concepts of 'perception', 'thinking' and 'action', yet they use them in subtly different ways. Although the idea of a loop perception-thought-action is questioned for good reasons, all those disciplines share some concept about cognitive interaction, information processing, and embodied or disembodied 'mind'.

As in AI there is a division between Symbolic AI (GOFAI: Good Old Fashioned AI, according to the detractors) and New (embodied) AI, in neurosciences and neurophysiology there have been a long lasting division between the 'behaviorist' school, more popular in Anglo-Saxon countries, and the 'German school', strongly influenced by the 'psychology of the gestalt'; probably both originate from the historical division between 'Anglo-Saxon' and 'Continental' philosophy.

The main ideas advocated here are that: first, it is not realistic to cope with problems in those disciplines without looking at what is going on in the neighboring ones, something that few people will object to; second, potentially more controversial, that we need a common conceptual framework and a new science: the science of physical embodied cognitive systems.

When we think to AI, we may probably consider as typical examples the Hanoi Tower planner or a chess player, following the historical defeat of G. Kasparov then the world chess champion, by a machine in 1996. Yet the most successful AI applications are probably in the field of Bayesian decision systems, e.g. Google search or more recently IBM Watson. It is has been shown, by many experiments, that the human (and mammalian) brain might be seen as a Bayesian decision system. A complex system like it might have evolved mainly to control movement, in particular walking and what roboticists call visual manipulation and grasping, see [6,7,8,12,13,15, 55].

Although there are other hypotheses, for example some recent results, [56], coming from the analysis of a large number of fossils, suggests that a very early leap in the mammalian brain dimensions might have actually be triggered by the needs of odor localization. To control movement in particular the human brain behaves in many experiments as it minimizes uncertainty, i.e. maximizing information, through Bayesian estimation, by comparing the predictions of actions' consequence with the actual effect of the action themselves and by smoothing transitions from perception to action, by optimizing energy consumption. Predictive and anticipatory behaviors show to be extremely important. From a Robotics standpoint, whatever the evolutionary role of motion control in the mammals, it is no surprise that it uses an important fraction of cerebral information processing resources. If we compare these findings in natural systems, with most artificial cognitive systems, the difference is not only a matter of computing power, but also the fact that, despite the fact that this has not yet well analyzed by researchers, the brain cognitive processes are actually embodied and intertwined with body dynamics. These kinds of processes have been studied from a different perspective in Robotics and New AI domain; think about the MIT, Delft and CMU biped under actuated walkers and other similar examples, [31].

As another, related, example, it is interesting to see how space representation is dealt with in some robotics researches and in some neurophysiology ones.

A particularly successful methodology for managing space in robotics, applied to mobile, usually wheeled, robots, is Simultaneous Localization and Mapping, SLAM. In those algorithms the position of a robot (an agent) is simultaneously reconstructed from a temporal series of noisy observations (coming from laser, odometry, monocular, unidirectional or stereo vision) through a statistic iteration process which as new observations come in refines continuously the inner model of the robot about the map of the surrounding environment and its position in the map. This is usually done with the assumption that the processes (the linearized robot dynamics) are linear and noise is Gaussian. The space is always assumed Euclidean, and, with the exception of some recent work, [52], the algorithms are tacitly and not questionably based on an underlying Euclidean space representation. This is usually also the case for visual grasping system algorithms, [53] the

systems which aim to perform the kind of action that many think was crucial for the evolution of the human brain: the intelligent manipulation and grasping of known and unknown objects.

On the contrary, we know from a significant amount of neurophysiology results, [46, 47], that the human brain manages three geometries for motion optimization in visual manipulation and grasping tasks: sometimes Euclidean, but more often Affine or Equi-Affine.

The brain does not always represent space as Euclidean. Does this mean that the robotics researcher community 'is wrong' or that more likely we need a higher level of abstraction and understanding of a common underlying reality? The reason why the human brain mainly relies, besides Bayesian decision methods, on a non Euclidean geometry for motion planning purposes is a consequence of some structural constraint in the neuronal architecture and or body structure, or there are good reasons to do that, for example due to energy optimization and predictive information maximization, for any intelligent system including artificial ones, robots?

The human brain, as far as we know, is the most sophisticated cognitive 'machine' on our planet; nevertheless the basic organizational principles are shared with more ancient living beings and are evolved on top of evolutionary earlier solutions. By the way, it is worth noticing that a 'machine' of this kind is closer to the concept of a high dimensionality adaptive complex system loosely coupled hierarchical network of networks than to a 'clock' machine like the model of Le Mettrie. This is the reason why complex system dynamics and network physics matter.

Important aspects chased by developmental psychology, evolutionary robotics and biology are related to evolutionary processes, actually neuroscience and neurophysiology works such as those recalled above are kind of black box instantaneous pictures of underlying system processes, which so far remain fundamentally unknown.

Although in many cases the prevailing paradigm in robotics, 'mutatis mutandis', may still be regarded as not much different from the 'automata' paradigm exemplified in fig. 2, in the modern form of a stack of mechatronics and machine learning, it is a widespread opinion that in order to achieve a level of dexterity, adaptability and robustness comparable to what we see in the natural domain we need a deeper scientific foundation, [60].

It is believed that this new foundation might be given by the new science of physical cognitive envisioned, in different forms, here and elsewhere, for example here [49].

2.2 A Short Comparative Survey of Some Philosophical Views

As already observed, some of the key issues in what are now regarded as scientific fields of investigation have been studied as philosophical topics for a long time. In this short survey we focus on a short not exhaustive list of philosophers whose interests and approaches are closer to scientific disciplines such as AI, Cognitive

Fig. 2 The Jaquet-Droz brothers' automata (built at the end of the XVIII century) are an example of the level of complexity of behavior and realistic appearance that a purely mechanical automata, based on gears, Geneva wheels, cams and belts can reach. Three of these automata (the writer, the drawer and the player) are conserved in the Neuchâtel Museum of Art and History. The writer, the most complex can be 'programmed' to write any given text with a maximum of 40 letters long. He inks his goose feather at regular times. His gaze follows the text while writing and move the head accordingly when he inks the pen. Similar examples of the same age are the Japanese Karakuri dolls (Courtesy: Neuchâtel Museum of Art and History).

science, Robotics and neurosciences with the purposes, recalled many times, of calling for a potentially fruitful comparison of the different approaches and their subsumption in a more comprehensive and deeper conceptual, philosophical and scientific framework. We will recall later, as usually as examples, how the problems of perception and 'sensory motor coordination' now regarded as scientific field of investigation have actually been analyzed already in a philosophical context. Moreover, it is interesting to notice that some recent discoveries in neurosciences and neurophysiology such as the importance of emotions in the regulation of cognitive and even sensory motor coordination processes, see below the short discussion on Damasio's work, were already proposed in philosophy on the basis of introspection and conceptual analysis. For example, [71], in "A Treatise of Human Nature", Hume aims to found a 'science of man' as a 'natural science', indeed anticipating nowadays' trends and states that that emotional drives direct reason, not the opposite: "Reason is, and ought only to be the slave of the passions." In his view 'ideas' were abstracted from the series of 'impressions' coming from

the senses, the only source of knowledge. In his view the "self," was nothing more than a set of sensations bundled together. We may even see here an early formulation of the 'symbol grounding' problem in enactive cognition.

From a different respect, Kant's 'transcendental method' is close to the mainstream approach in cognitive science: in order to study the mind he infers the conditions necessary for experience. Unobservable mental mechanisms are postulated to explain 'economically' the observed behavior. 'Transcendental apperception' as the unified perception of all experience by the subject, and the idea that 'representation' is 'representation to a subject' thus postulating a self, if not a conscious subject, as a prerequisite for what in modern words we may call 'cognition' make his thought less prone to circularity issues than many more contemporary analysis. The idea of leveraging on conceptual analysis and introspection to deduce the 'a priori' condition to know the world, and to develop scientific knowledge such as the models developed by physics, is still significant.

Kant's view, which actually doesn't say anything about the material support of the cognitive subject, in this sense is not 'per se' a dualistic or idealistic view.

Surprisingly, Kant' s ideas on self and consciousness had no influence until the past century in the work of Wittgenstein and later Shoemaker.

Merleau-Ponty, [3], in opposition with the Cartesian dualism and in analogy with embodied and enactive cognition, observed that the subject is actually embodied and actually that body and mind are inherently intertwined: the 'mind' can be seen as the 'intentional stance' of the body. Phenomena are not abstract a-temporal 'objects', which exist independently outside of the subject, but correlations between sensory motor activities, the body and the external environment.

This standpoint is very sympathetic to that of New AI and New Robotics.

As much sympathetic as Locke and Husserl are, both providing views on the 'mind' and the 'self' which are really, as in particular Merleau-Ponty's ones, very inspiring for modern neuroscience researchers like Rizzolatti, [54], and in New AI and Robotics. Locke, usually credited to have been the first to do so, depicted the 'self' as a continuous series of conscious states building knowledge on a 'tabula rasa'. Husserl also sees object as a grouping of perceptual and utility aspects ('affordances'?) strictly related to our intentions to manipulate or simply observe the world. These positions share the limit that they are centered on the 'cognitive/perceiving' function of an individual 'agent' and they might underestimate the importance in cognitive processes in the humans, and other animals, of network/collective processes such as those discussed by Bateson with his concept of 'ecology of mind', [68], and Marx's idea of a collective learning through the 'praxis'.

It is worth to notice that we do not naively claim that scientific research is validating one or another philosophical view: we want to warn that those preexisting analysis, sometimes really deep and which as in the cases above sound very meaningful to a contemporary cognition science researcher, should be seriously considered by scientist investigating similar topics with different methods. More relevant the fact that although there might be analogies with the process, which led from philosophy of nature to modern sciences, philosophical investigations on mind might have a different status where they focus on the circularity issues

implicit in any gnoseology, at least. Moreover, not only some recent philosopher who share our ‘zeitgeist’ appear familiar, but also unexpectedly other much older. For example, in a famous quote, Aristotle said: “If every tool, when ordered, or even of its own accord, could do the work that befits it, just as the creations of Daedalus moved of themselves . . . If the weavers' shuttles were to weave of themselves, then there would be no need either of apprentices for the master workers or of slaves for the lords.” If we read it today “The part of the quote "or even of its own accord” is elsewhere translated as "or by seeing what to do in advance" etc. (you may find many translations). I think this is an important part of the quote, so it's good to go back to the original text: Aristotle uses the word "προαισθανόμενον" – proaisthanomenon this means literally: pro = before, aisthanomenon = perceiving, apprehending, understanding, learning (any of these meanings in this order of frequency) in my view it is clearly a word that is attributed to intelligent, living agents....i.e. ones with cognitive abilities (!)”, [57].

It is difficult to see the modern reading of a famous passage in Aristotle’s Politics as a mere arbitrary attribution of modern ideas to an old text, it seems more likely a rediscovery in a scientific context of the meaning of a philosophical analysis, which passed almost unnoticed in its context for its limited philosophical implications, but looks enlightening in another cultural environment.

None of these conceptual frameworks, and of those omitted for space reasons, is ‘neutral’ or not relevant with respect to the general problem of identifying the general conditions for a material system to be intelligent, cognizant and ‘sentient’ and they are source of inspiration from a conceptual, scientific and even engineering point of view. They have to be compared, if not reconciled, with the assumptions of a wide set of disciplines and the conceptual foundation of the new science of physical cognitive systems envisioned here and elsewhere.

3 A Few Hints towards a Synthesis

Which might be the common underlying ground of these wide set of ‘phenomena’, discovered by such diverse methods such as experimental scientific research, synthesis of artifacts, philosophical analysis based on concept clarification and introspection?

Natural cognition might be seen as an emerging adaptive (meta) process of loosely coupled networks of embodied and situated agents. This is suggested by a number of conceptual analysis, scientific researches and experimental results, [24,29]. Embodied biological neural networks, whose complexity is significantly higher of that of the artificial neural networks as they are usually modeled by researchers, are, by, far the most widespread ‘paradigm’ for implementing cognitive processes in nature. Of course, see [43], it is possible that ‘evolution worked with what was available’ and it is possible that not all the characteristics of ‘cognitive system implementation’ are necessary for autonomous cognitive behavior, yet as the natural systems have characteristics of adaptivity and robustness that so far we were not able to emulate, it make sense to try to ‘reverse engineer’ them.

We are led to ask ourselves which characteristics of natural systems are actually necessary for autonomous behavior, for the emerging of a 'self' and for consciousness.

Artificial cognitive systems engineered within the AI and the Robotics domain, are usually based on a different paradigm: a great variety of algorithms for the processing of probabilistic enunciates and the optimization of stochastic indexes, 'hard coded' Bayesian inference networks in AI and a stack of mechatronic devices, control theory based algorithms and AI in robotics. The main difference with their natural counterparts is the lack of self-organization (and much more limited exploitation of parallelism in computation and of under actuation in physical interaction). This is no surprise if we consider that the theory of computation, [42], or that of statistical learning, [30], don't include the physical system performing the computation or learning a given environment. These limitations looks like originating by 'philosophical prejudices': researchers tend to stick with the 'common sense' of the society within which they operate. There are, anyhow exceptions. In the past years Pfeifer and other researchers, [22,23], have shown the importance of 'embodiment' and 'situatedness' in natural intelligent systems.

It is, maybe, more critically important the fact that the basic assumption in the design of those systems (including recent celebrated successes like IBM's Watson, [45]) require a 'stage setting' by the human designer of the system who is supposed to know in advance (thanks to a rather different system implementation, his own mind-brain-body system) which kind of specific problems the system will encounter and which rule base will allow to cope with them.

The emerging of intelligence, cognition, 'sentience' and meaning should be explained on the basis of the communication processes between autonomous cognizant (loosely) networked agents, the network of networks of environmental relations. It could be modeled as the evolutionary self-organization of coevolving situated and embodied low level information processing, physically distributed among the inter communicating agents, motivated and initiated by physical finalized interactions with the environment.

The idea that intelligence and learning capabilities might emerge from some evolutionary process was actually already proposed by Turing, [67], and the model proposed here is in line with Bateson' s concept of an ecology of mind. These ideas are discussed with some more details here: [29, 50].

These self-organization processes in network of networks of loosely coupled agents are likely to occur at many scales in size (from micro regulation in the cell nucleus to the tissue differentiation in the embryo, to the emergence of cognitive processes in the brain). Also, despite the conceptual and mathematical difficulties, these principles should guide the design of artificial cognitive systems.

As an example we may speculate that the non Euclidean geometric optimization of motion control is due to an emerging self organization process optimizing not only energy and other mechanics metrics, like stress strain etc, but also information metrics 'a la Shannon'. As another example emotions might be an emerging coordination process between many task optimizing the same metrics.

Our purpose should be to define the conceptual framework, in the epistemological and broadly philosophical sense, to define the conditions for cognition,

sentience, self and even consciousness in a material systems and to identify a set of coherent scientific models covering the phenomena now approached with different languages/jargons in different disciplines, but essentially dealing with intelligent autonomous behaviors of material systems. As told above the demarcation line between philosophical and scientific investigation, seems more blur and fuzzy than in the case of cognitive science than in the case of 'philosophy of nature'.

4 Open Issues

Even from the necessarily short discussion above it is apparent that the program of developing a unified conceptual framework as a foundation for a new unified scientific domain poses serious challenges. Despite the fact that we may have some ideas about an unified framework, the diversity of 'ontology' and methodological approach between fields such as neuroscience and robotics, as instance, and the pre paradigmatic stage of cognitive sciences, make still premature to outline an 'ontology' and an epistemology for the new advocated science of physical cognitive systems.

In the previous paragraph it has been proposed that cognitive processes emerge in physical systems as a collective organizational process of network of networks of loosely coupled (active) agents and it has been postulated that self-organization is a necessary attribute of an autonomous cognitive system. There are good reasons to think so, yet this should be regarded at this point more as a research program than an acceptable and well-corroborated new scientific paradigm based on experimental evidence. This is due to a number of open issues. Some of the more compelling ones, in the opinion of the author, are listed here below. Others would provide a different list.

Complexity or 'Simplexity'?

The broad idea that cognitive processes, 'self' and 'consciousness' might be emerging organized processes from the collective behaviors of wide network of networks of independent agent, make somehow natural to model them by means of the conceptual and mathematical language of complex system theory. Under many respects complex system theory helps the understanding of the cognitive processes in physical systems (both natural and artificial), yet it must be noticed that, in natural cognitive systems there might be something more subtle at work: what, for example Alain Berthoz, calls 'simplexity', [63]. The complexity of the world is radically simplified in the agent perspective through a number of simplifying principles. This allows keeping the computational load low enough to be managed.

One of the most important of these simplifying 'design solutions' applied in natural cognitive systems is the radical simplification of the perception-action link by limiting the perceptual capabilities of the natural autonomous agent to its 'umwelt'.

Umwelt

The concept of ‘umwelt’ (um- ‘around’, welt ‘world’), [61], was introduced by Jakob Von Uexküll at the beginning of the 20th century and has recently raised some new interest in the neurophysiology community, [48]. He is considered the founder of the so called ‘biosemiotic’, referring to semiotic science grounded in the biological world, as a matter of fact we only know physical systems able to manipulate ‘signs’ and the by far more effective are the biological ones. The ‘umwelt’ is the environment-world as it perceived by a given animal. It is tightly related to what the animal can do in the world and what it can sense. What it can sense is what is needed to perform the actions necessary for its survival. Any animal has a different um-welt (including humans: we don’t see radio waves and actually we only perceive a very limited portion of the electromagnetic spectra, for example). The paradigmatic example is the tick’s umwelt. The tick uses the sensitivity to light of its skin to reach an observation point (e.g., the top of a blade of grass) She senses the arrival of a ‘prey’ from the smell of butyric acid, which emanates from the sebaceous follicles of mammals, the she senses this she falls down freely until she enter in contact with the skin of a mammal and can thanks to touch find a proper place to embed into the skin of the prey. The ‘world’, ‘Umwelt’, of the tick is thus limited, to an approximate gradient of light, an approximate gradient of butyric acid and a texture haptic sense.

His views show analogies and had some influence on the work of philosophers like Martin Heidegger, Maurice Merleau-Ponty, Gilles Deleuze and Félix Guattari and neurophysiologists like Berthoz and collaborators.

It seems that the concept of ‘Umwelt’ might be extremely useful in the reverse engineering of natural cognitive systems and the design of artificial one, yet this ‘view’ is not widely adopted. Moreover this should be referred to the reference framework of the emerging of coordination processes in the complex dynamics of (sometimes massively) multiagent systems.

Body and Mind

The Cartesian view about the distinction between body and mind is not popular among philosophers and psychologists, yet it is generally an untold assumption and a material fact in ‘traditional’ symbolic AI and Robotics. In any case the body-mind nexus has to be modeled in term of an extended dynamical systems theory.

Consciousness, ‘self’, ‘sentience’

The concept of consciousness is a traditional topic in philosophy [72, 70], psychology, and is deeply investigated in neurosciences, while it is a ‘marginal’ topic in AI and Robotics, and a ‘slippery’ topic in cognitive sciences. It is interesting to notice how hypotheses similar to those based on not scientifically structured observation, conceptual analysis and introspection such as thus of Hume have been somehow experimentally tested in recent times, by means of structural neuroimaging/neuroanatomy, experimental neuroanatomy neuropsychology and functional

neuroimaging. For example by Damasio, [62], who is carrying out an investigation on the basic material (neural) underpinning of mind, (protoself), self and consciousness by means of scientific experimentation.

In his view emotions are part of a homeostatic regulation process based on reinforcement learning process (reward/punishment in his terms). He sees (like James) 'feelings' as a synthetic representation of the 'body' state, actual and 'simulated'.

From this kind of stand point Rizzolatti's et al.,[54], results on mirror neurons can be seen as application of this body state simulation process.

On the other side Tononi, [44], proposes a metrics with clinical aims based on information metrics of variety and brain-range integration.

Which minimum degree of 'self awareness' is necessary to achieve a given degree of autonomous behavior of a given ecology of agents in a given environment is an open issue for physical cognitive systems.

Not 'just' Cognition

Where psychology and psychoanalysis fit? Emotions have been considered in Robotics only recently, while they have been a focus of interest for psychology, psychoanalysis and philosophy for a long time. Actually they are also an important matter of study for neurophysiology and neurosciences. An important question is if we should regards emotions as detached from cognitive capabilities, as in mainstream emotional synthesis systems in AI and Robotics, or whether in the context of self-organizing cognitive processes they are necessary emerging regulator processes.

Epistemological Issues

Serious reasons of concern are epistemological issues. Why should we care about 'scientific methodology' in the new science of physical cognitive systems or in particular in cognitive sciences and robotics research?

Which role should have the synthetic approach ('understand by building') of AI and Robotics with respect to the more traditional experimental method applied in neurosciences or, at the other extreme, the case-by-case dialogic approach of the various current of psychoanalysis?

In general in AI and Robotics, we are not always able to verify whether and by which measure proposed new procedures and algorithms constitute a real advancement and can be used in new applications, [51]. According to which metrics and by which procedures can we do comparisons between natural and artificial systems?

Even in the engineering sense of a set of strategies for good experimental design practices and a do-it-yourself approach prevails.

How we can exploit epistemological models coming from Biology and extend them?

How should analysis and reverse engineering of natural systems and the synthesis of engineering artifacts live together?

How to frame this in the context of complex (or simplex) adaptive networked systems?

Mathematical Issues

The modeling of self-organization processes in loosely coupled network of agents from a mathematical standpoint is not trivial and probably there are not yet coped challenges to overcome. In particular this makes difficult to design artificial systems inspired by this paradigm and experimentally validate the hypotheses, in particular in life sciences, including neuroscience.

Circularity Issues

"The mind-stuff of the world is, of course, something more general than our individual conscious minds... It is necessary to keep reminding ourselves that all knowledge of our environment from which the world of physics is constructed, has entered in the form of messages transmitted along the nerves to the seat of consciousness... Consciousness is not sharply defined, but fades into sub consciousness; and beyond that we must postulate something indefinite but yet continuous with our mental nature... It is difficult for the matter-of-fact physicist to accept the view that the substratum of everything is of mental character. But no one can deny that mind is the first and most direct thing in our experience, and all else is remote inference."

Sir A.S. Eddington, [68]

This quote from a famous physicist of the beginning of the past century on the one hand underlines the general importance of the discussion here and in general of cognitive sciences and their paradigms, on the other hand raise indirectly the attention on a potential circularity issue in this discussion: the explanatory models applied to the human mind are actually a product of the mind itself. This also applies to the philosophical analysis, but even old philosophers such as Kant seem much more aware of those potential problems than many contemporary scientist (the reverse engineer working in psychology, neuroscience, etc. and the synthetic designer of artificial systems working in AI, Robotics, Cognition etc.).

Even the information driven self-organization methods and in general those based on information metrics 'a la Shannon', [37, 38, 39], rely on a concept of 'information' that, in a naïve interpretation, assume an 'observer' which is actually what has to be modeled. This can be overridden, but at the price of a subtle reinterpretation, [58].

5 Discussion and Future Work

"How does it happen that a properly endowed natural scientist comes to concern himself with epistemology? Is there not some more valuable work to be done in his specialty? That's what I hear many of my colleagues ask, and I sense it from many more. But I cannot share this sentiment. When I think about the ablest students whom I have encountered in my teaching — that is, those who distinguish themselves by their independence of judgment and not just their quick-wittedness — I can affirm that they had a vigorous interest in

epistemology. They happily began discussions about the goals and methods of science, and they showed unequivocally, through tenacious defense of their views, that the subject seemed important to them.

Concepts that have proven useful in ordering things easily achieve such authority over us that we forget their earthly origins and accept them as unalterable givens. Thus they might come to be stamped as "necessities of thought," "a priori givens," etc. The path of scientific progress is often made impassable for a long time by such errors. Therefore it is by no means an idle game if we become practiced in analyzing long-held commonplace concepts and showing the circumstances on which their justification and usefulness depend, and how they have grown up, individually, out of the givens of experience. Thus their excessive authority will be broken. They will be removed if they cannot be properly legitimated, corrected if their correlation with given things be far too superfluous, or replaced if a new system can be established that we prefer for whatever reason." A. Einstein, [64]

The words above from Einstein, with early 20th physics in mind, in a period of deep paradigmatic change and fast progress of physics, might have been written today thinking at the condition of the wide spectrum of disciplines, so far distinct, which should provide foundation to the new science of physical cognitive systems. There is no real progress without critical thought and if we want that AI and Robotics do not stagnate, and that neuroscience and neurophysiology exploit their potential to reverse engineer the human and mammalian brain, we have a desperate need of critical thought (from 'reference ontology' to 'experimental method') on the current basic, often untold, assumptions of research in those fields.

Despite the diversity of concepts, theoretical approaches and experimental methods and practicalities, there are many convergent ideas and common problems, as we tried to recall above, which would benefit from a unified perspective.

There are good reasons to think that a unifying paradigm may come from the study of emerging self organization complex networks of loosely coupled agents, yet, as we have argued above, there are a number of challenging issues to deal with.

The scientific enterprise is now somehow close to unbundle the basic foundation of our consciousness and of our apperception of reality, and, it is clear that there are some circularity issues with the possible 'explanations', at least.

We have in front of us deep problems, scientific and philosophical, which are not 'easier' than those with which our predecessors were able to cope in Galileo's and Newton's age. The prize for unbundling those issues might be a new industrial, economical and societal revolution.

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