Scientific “Agendum” of Data Science

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Data on nuclear cross section have integrated metals, ceramics, waters and other materials to form various nuclear reactors, which is a basic for nuclear engineering. Data on intrinsic properties of substances are used to link extrinsic properties of substances and structure-sensitive engineering properties of defects as fundamental constants have been defined in a network of elaborate experiments and models in science. These understandings have driven me to data activities since 1970 when I at first became to know CODATA by name, and it is a good time now for me review the committed works in these 37 years and write down my personal gagendumh reflecting the re-view so as to have more collaborators for the next milestone.

As scientific agendum of CODATA, we have added an aspect gdata and societyh explicitly through such opportunities of WSIS(World Summit on the Information Society)s and lessons on tragedies, namely, suffering from natural disasters and epidemics. Not only by global warming problems pointed out clearly by IPCC (Intergovernmental Panel on Climate Change) but also by other global issues as known well partly by UN MDGs(the eight Millennium Development Goals), we have become to know the necessity of linking scientific, technical, economic, social and political agenda with proper missions and guidelines for the society. Here human-centered reorganizations of domain-differentiated sciences from natural sciences to social sciences, are requested to be carried out, where and when we need common data for the proper and holistic reorganization to reach right decisions and consensus of society. If we do not share common data on global warming effects, we cannot write down our remedies against inconvenient truths and establish flexible and steady roadmaps for the sustainable society. It is necessary for us experts to write down proper remedies together by linking such associated scientific domains as politics, laws, ethics, economics, environmental sciences, ecologies, civil engineering, manufacturing, waste management and so on and complimenting missing links there for better solutions. And as a consequence of such efforts we may come to create a new scientific domain gdata-driven sustainable scienceh to design and manage the society properly. It is really requiring us continuous big efforts with challenging spirits to start everything from facts and data, which is our raison dfetre and concerns our identity as data scientists.

However, the above agendum essentially has already been associated to our core activities. Data and knowledge corresponding missing links of domain specific sciences have been daily works of CODATA. For example,

- fundamental constants have been compiled reflecting advances of precise measurements and basic sciences, and also higher coherences of scientific models, which has resulted in creating new sciences like nano-sciences, spintronics and other specialized scientific domains, and also several key standards for the information society, namely, radio wave standards, current, voltage and so on,
- spectra data and diffraction data have guided us to get microstructural information on substances and materials, and also on life. Together with models and interatomic potentials derived from first principles calculation, new scientific and technical fields have been exploited rapidly, and application areas are spreading widely over drug design, defect theory, fracture dynamics, materials design, process design, earth sciences, and even in bioscience to see the origin of life and medical diagnostics.
- many exemplars in biosciences to get insight through using common data: arabidopsis thaliana data for evolving botany; RNA data to link DNA and protein, and consequently associated with disease and health; data on Tradescantia ohiensis and/or nude mice for irradiation effects, and by taking advantage of recent advances in genomics, proteomics biophysics and biochemistry, an breakthrough is going on to overcome limitations of epidemiological survey based on statistics.

Data-oriented statistical approaches are combined with scientific models and practical monitoring, and traditional established safety/risk/reliability standards are changing into proactive and dynamic adaptive standards. Safety/risk issues in medical services, nuclear reactors, aircrafts, company managements, energy resource security and so on can be dealt with in a similar way. Openness and transparency of many disciplines and scientific domains promoted by e-science projects and so called global information commons are prerequisites for a revolution of sciences by the 7 billion people. Devices for the revolution might be something creative of emerging wisdoms and welling up emotions in the internet, which may be more than such knowledge management approaches as ontology, metadata, object-oriented approach, semantic-web, common sense reasoning and so on.

Through evaluation of fundamental constants we are integrating quantum worlds, atomistic worlds and macroscopic worlds quantitatively, where scientific disciplines and domains are networked with a certain consistency. Through preparation of geometric data of parts with properties we can design an artifacts and assemble the available parts into the artifacts of integrity and cost-effective performances, where domain differentiated engineering disciplines are integrated to establish manufacturing industries. Design and maintenance of landscapes, cities, countries, regional environments and global climates are used to be carried out in a similar way, namely, sharing data by stakeholders and coordinating different views and opinions by the shared common data. Quality of data matters every time and everywhere. Gold in, gold out. Reasonable estimations of uncertainties on data may produce better results

and outcomes. The more the problem to be solved is uncertain, the more we should become flexible. Evidence-based deterministic approaches do not work effectively, and adaptive and heuristic approaches work better coupled with in situ data capture, evaluation, and quick decision and timely actions. Holistic creativity as a group is a key for a success of the group, where practical maintenance of data quality for proper decision is important. Time constants of data life cycle are becoming shorter, and diversities of stakeholders and complexities of data are increasing. New disciplines are to be continuously created by taking advantage of available data and devices so as to prepare solutions on time. Without proper managements of continuously produced big data, and without productivity of new disciplines based on data, we cannot solve important problems of the world. Data science may play an important role there.

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2

Discovering and Communicating through Multimodal Abduction

The Role of External Semiotic Anchors and Hybrid Representations

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Summary. Our brains make up a series of signs and are engaged in making or manifesting or reacting to a series of signs: through this semiotic activity they are at the same time engaged in "being minds" and so in thinking intelligently, in communicating and in extracting chances from the einvironment. An important effect of this semiotic activity of brains is a continuous process of "externalization of the mind" that exhibits a new cognitive perspective on the mechanisms underling the semiotic emergence of abductive processes of meaning formation. To illustrate this process I will take advantage of the analysis of some aspects of the cognitive interplay between internal and external representations and communications. I consider this interplay critical in analyzing the relation between meaningful semiotic internal resources and devices and their dynamical interactions with the externalized semiotic materiality suitably stocked in the environment. Hence, minds are material, "extended" and artificial in themselves. A considerable part of human abductive thinking is occurring through an activity consisting in a kind of reification in the external environment (that originates what I call *semiotic anchors*) and a subsequent re–projection and reinterpretation through new configurations of neural networks and chemical processes. I also illustrate how this activity takes advantage of hybrid representations and how it can nicely account for various processes of creative and selective abduction, central to communications processes and chance/risk extraction, bringing up the question of how *multimodal* aspects involving a full range of sensory modalities are important in hypothetical multidisciplinary reasoning.

2.1 The Centrality of Abduction in Multidisciplinary Hypothetical Reasoning

If we decide to increase knowledge on both cognitive and semiotic aspects of multidisciplinary hypothetical reasoning it is necessary to develop a cognitive model of creativity able to represent not only "novelty" and "unconventionality", but also some features commonly referred to as the entire creative process, such as the hybrid

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modeling activity developed in the communicative interplay between internal and external representations. The philosophical concept of *abduction* may be a candidate to solve this problem, and offers an approach to model creative processes of meaning generation and communication in a completely explicit and formal way.

A hundred years ago, C. S. Peirce [8] coined the concept of abduction in order to illustrate that the process of scientific discovery is not irrational and that a methodology of discovery is possible. Peirce interpreted abduction essentially as an "inferential" *creative process* of generating a new hypothesis. Abduction has a logical form – fallacious, if we model abduction by using classical syllogistic logic – distinct from deduction and induction. Reasoning which starts from reasons and looks for consequences is called *deduction*; that which starts from consequences and looks for reasons is called *abduction*.

Abduction – a distinct form of reasoning – is the process of *inferring* certain facts and/or laws and hypotheses that render some sentences plausible, that *explain* or *discover* some (eventually new) phenomenon or observation; it is the process of reasoning in which explanatory hypotheses are formed and evaluated. There are two main epistemological meanings of the word abduction [20]: 1) abduction that only generates "plausible" hypotheses ("selective" or "creative") and 2) abduction considered as inference "to the best explanation", which also evaluates hypotheses (cf. Figure 2.1). An illustration from the field of medical knowledge is represented by the discovery of a new disease and the manifestations it causes which can be considered as the result of a creative abductive inference. Therefore, "creative" abduction deals with the whole field of the growth of scientific knowledge. This is irrelevant in medical diagnosis where instead the task is to "select" from an encyclopedia of pre-stored diagnostic entities. We can call both inferences ampliative, selective and creative, because in both cases the reasoning involved amplifies, or goes beyond, the information incorporated in the premises.

I have introduced [20] the concept of *theoretical abduction* as a form of neural and basically internal processing. I maintain that there are two kinds of theoretical abduction, "sentential", related to logic and to verbal/symbolic inferences, and

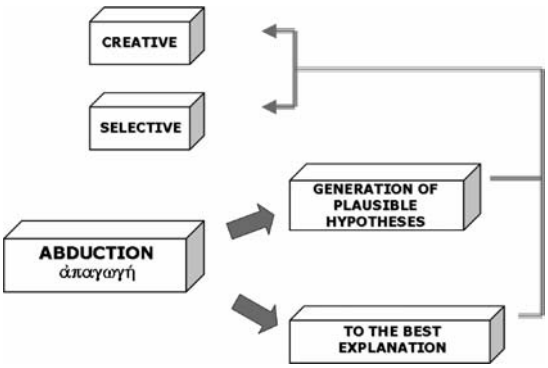

Fig. 2.1. Creative and selective abduction.

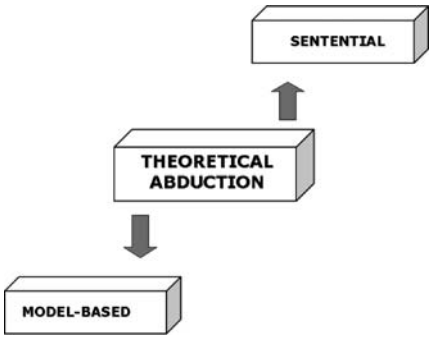

Fig. 2.2. Theoretical abduction.

"model-based", related to the exploitation of models such as diagrams, pictures, etc, cf. below in this paper, section 2.1.2 and subsection 2.3 (cf. Figure 2.2).

Theoretical abduction certainly illustrates much of what is important in creative abductive reasoning, in humans and in computational programs, but fails to account for many cases of explanations occurring in science when the exploitation of environment is crucial. It fails to account for those cases in which there is a kind of "discovering through doing", cases in which new and still unexpressed information is codified by means of manipulations of some external objects I have called *epistemic mediators* [20]. The concept of *manipulative abduction*[1] captures a large part of everyday and scientific thinking where the role of action is central, and where the features of this action are implicit and hard to be elicited: action can provide otherwise unavailable information that enables the agent to solve problems by starting and by performing a suitable abductive process of generation or selection of hypotheses.

In section 2.4 I will describe how manipulative abduction can nicely account for communication and risk/chance extraction in the relationship between meaningful behavior and dynamical interactions with the environment. The following sections illustrate that at the roots of the creation of new meanings there is a process of externalization that exhibits a new cognitive description of the mechanisms underling the emergence of meaning processes through semiotic delegations to the environment. Hence, interesting (and new) information and knowledge packages are generated and stored over there in the external human niches, in various supports more or less accessible that can be picked up in further communicative and chance/risk discovering processes.

2.1.1 The "Internal" Side of Creative Reasoning

Throughout his career Peirce defended the thesis that, besides deduction and induction[2], there is a third mode of inference that constitutes the only method for really

[1] Manipulative abduction and epistemic mediators are introduced and illustrated in [21] and [20].

[2] Peirce clearly contrasted abduction with induction and deduction, by using the famous syllogistic model. More details on the differences between abductive and inductive/deductive inferences can be found in [22] and [20].

improving scientific knowledge, which he called *abduction*. Science improves and grows continuously, but this continuous enrichment cannot be due to deduction, nor to induction: deduction does not produce any new idea, whereas induction produces very simple ideas. New ideas in science are due to *abduction*, a particular kind of non-deductive[3] inference that involves the generation and evaluation of explanatory hypotheses. Many attempts have been made to model abduction by developing some formal/sentential tools in order to illustrate its computational properties and the relationships with the different forms of deductive reasoning [see, for example, [23]. Some of the formal models of abductive reasoning are based on the theory of the *epistemic state* of an agent [24], where the epistemic state of an individual is modeled as a consistent set of beliefs that can change by expansion and contraction (*belief revision framework*).

2.1.2 Model-Based Abduction and its External Dimension

We do not have to limit ourselves to the *formal/sentential* view of theoretical abduction but we have to consider a broader *inferential* one: the *model-based* sides of creative abduction (cf. below).

From Peirce's philosophical point of view, all thinking is in signs, and signs can be icons, indices or symbols. Moreover, all inference is a form of sign activity, where the word sign includes "feeling, image, conception, and other representation" [8, 5.283], and, in Kantian words, all synthetic forms of cognition. That is, a considerable part of the thinking activity is model-based. Of course model-based reasoning acquires its peculiar creative relevance when embedded in abductive processes, so that we can individuate a *model-based abduction*. Hence, we must think in terms of model-based abduction (and not in terms of sentential abduction) to explain complex processes like scientific conceptual change. Different varieties of *model-based abductions* [25] are related to the high-level types of scientific conceptual change [see, for instance, [26].

Following Nersessian [9, 27], the term "model-based reasoning" is used to indicate the construction and manipulation of various kinds of representations, not mainly sentential and/or formal, but mental and/or related to external mediators. Obvious examples of model-based reasoning are constructing and manipulating visual representations, thought experiment, analogical reasoning, but also for example the so-called "tunnel effect" [28], occurring when models are built at the intersection of some operational interpretation domain – with its interpretation capabilities – and a new ill-known domain.

Manipulative abduction [20] - contrasted with theoretical abduction - happens when we are thinking through doing and not only, in a pragmatic sense, about doing. So the idea of manipulative abduction goes beyond the well-known role of experiments as capable of forming new scientific laws by means of the results (nature's answers to the investigator's question) they present, or of merely playing a predictive

[3] Non-deductive if we use the attribute "deductive" as designated by classical logic.

role (in confirmation and in falsification). Manipulative abduction refers to an extra-theoretical behavior that aims at creating communicable accounts of new experiences to integrate them into previously existing systems of experimental and linguistic (theoretical) practices. The existence of this kind of extra-theoretical cognitive behavior is also testified by the many everyday situations in which humans are perfectly able to perform very efficacious (and habitual) tasks without the immediate possibility of realizing their conceptual explanation. In the following sections manipulative abduction will be considered from the perspective of the relationship between internal and external representations.

2.2 Mimetic and Creative Representations

Human brains organize themselves through a semiotic activity that is reified in the external environment and then re-projected and reinterpreted through new configurations of neural networks and chemical processes. I also think the externalization of mind can nicely account for low-level semiotic processes of meaning creation, bringing up the question of how could higher-level processes be comprised and how would they interact with lower-level ones.

2.2.1 External and Internal Representations

I have illustrated in a previous paper [7] dealing with some paleoanthropological issues that through the mediation of the material culture the modern human mind for example can arrive to *internally* "think" the new complicated abstract meaning of animals and people at the same time. We can account for this process of externalization from an impressive cognitive point of view.

I maintain that representations are external and internal. We can say that

- *external representations* are formed by external materials that express (through reification) concepts and problems already stored in the brain or that do not have a *natural home* in it;
- *internalized representations* are internal re-projections, a kind of recapitulations, (learning) of external representations in terms of neural patterns of activation in the brain. They can sometimes be "internally" manipulated like external objects and can originate new internal reconstructed representations through the neural activity of *transformation* and *integration*.

This process explains why human beings seem to perform both computations of a *connectionist* type[4] such as the ones involving representations as

[4] Here the reference to the word "connectionism" is used on the plausible assumption that all mental representations are brain structures: verbal and the full range of sensory representations are neural structures endowed with their chemical functioning (neurotransmitters and hormones) and electrical activity (neurons fire and provide electrical inputs to other neurons). In this sense we can reconceptualize cognition neurologically: for example the

- (I Level) *patterns of neural activation* that arise as the result of the interaction between body and environment (and suitably shaped by the evolution and the individual history): pattern completion or image recognition,

and computations that use representations as

- (II Level) *derived combinatorial syntax and semantics* dynamically shaped by the various external representations and reasoning devices found or constructed in the environment (for example geometrical diagrams); they are neurologically represented contingently as pattern of neural activations that "sometimes" tend to become stabilized structures and to fix and so *to permanently belong to the I Level* above.

The I Level originates those *sensations* (they constitute a kind of "face" we think the world has), that provide room for the II Level to reflect the structure of the environment, and, most important, that can follow the computations suggested by these external structures. It is clear we can now conclude that the growth of the brain and especially the synaptic and dendritic growth are profoundly determined by the environment.

When the fixation is reached the patterns of neural activation no longer need a direct stimulus from the environment for their construction. In a certain sense they can be viewed as *fixed internal records* of *external structures* that *can exist* also in the absence of such external structures. These patterns of neural activation that constitute the I Level Representations always keep record of the experience that generated them and, thus, always carry the II Level Representation associated to them, even if in a different form, the form of *memory* and not the form of a vivid sensorial experience. Now, the human agent, via neural mechanisms, can retrieve these II Level Representations and use them as *internal* representations or use parts of them to construct new internal representations very different from the ones stored in memory [29].[5]

I think there are two basic kinds of external representations active in this process of externalization of the mind: *creative* and *mimetic*. Mimetic external representations mirror concepts and problems that are already represented in the brain and need to be enhanced, solved, further complicated, etc. so they sometimes can creatively give rise to new concepts and meanings. In the examples I will illustrate in the following sections it will be clear how for instance a mimetic geometric representation can become creative and give rise to new meanings and ideas in the hybrid interplay between brains and suitable "cognitive niches"[6] that consequently are appropriately reshaped.

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solution of a problem can be seen as a process in which one neural structure representing an explanatory target generates another neural structure that constitutes a hypothesis for the solution.

[5] The role of external representations has already been stressed in some central traditions of cognitive science and artificial intelligence, from the area of distributed and embodied cognition and of robotics [17, 18, 30] to the area of active vision and perception [1, 31].

[6] This expression, used in the different framework of the problem of language as biological adaptation to the environment appears very appropriate also in this context [3, 4].

In the following section I will illustrate some fundamental aspects of the interplay above in the light of basic semiotic and thus communicative aspects of abductive reasoning.

2.3 Model-Based Abduction, Semiosis, Communication

What exactly is model-based abduction from a philosophical and cognitive point of view? I have already said that Peirce stated that all thinking is in signs, and signs can be icons, indices, or symbols and that all *inference* is a form of sign activity, where the word sign includes "feeling, image, conception, and other representation" [8, 5.283]. In this light it can be maintained that a considerable part of the creative meaning processes is *model-based*. Moreover, a considerable part of meaning creation processes (not only in science) occurs in the middle of a relationship between brains and external objects and tools that have received cognitive and/or epistemological delegations (cf. the previous and the following subsection). Let me address some philosophical issues.

Following this Peircian perspective about inference I think it is extremely useful from a cognitive point of view to consider the concept of reasoning in a very broad way (cf. also [32, p. 8]). We have three cases:

1. reasoning can be fully conscious and typical of high-level worked-out ways of inferring, like in the case of scientists' and professionals' performances;
2. reasoning can be "acritical" [8, 5.108], which includes every day inferences in conversation and in various ordinary patterns of thinking;
3. reasoning can resort to "operations of the mind which are logically analogous to inference excepting only that they are unconscious and therefore uncontrollable and therefore not subject to logical criticism" [8, 5.108].

Immediately Peirce adds a note to the third case "But that makes all the difference in the world; for inference is essentially deliberate, and self-controlled. Any operation which cannot be controlled, any conclusion which is not abandoned, not merely as soon as criticism has pronounced against it, but in the very act of pronouncing that decree, is not of the nature of rational inference – is not reasoning" (*ibid.*).

As Colapietro clearly states [33, p. 140], it seems that for Peirce human beings semiotically involve unwitting trials and unconscious processes. Moreover, it seems clear that unconscious thought can be in some sense considered "inference", even if not rational; indeed, Peirce says, it is not reasoning. Peirce further indicates that there are in human beings multiple trains of thought at once but only a small fraction of them is conscious, nevertheless the prominence in consciousness of one train of thought is not to be interpreted an interruption of other ones.

In this Peircian perspective, which I adopt in this essay, where inferential aspects of thinking dominate, there is no intuition, in an anti-Cartesian way. We know all important facts about ourselves in an *inferential* abductive way:

> [...] we first form a definite idea of ourselves as a hypothesis to provide a place in which our errors and other people's perceptions of us can happen. Furthermore, this hypothesis is constructed from our knowledge of "outward" physical facts, such things as the sounds we speak and the bodily movements we make, that Peirce calls signs [32, p. 8].

Recognizing in a series of *material*, physical events, that they make up a series of signs, is to know the existence of a "mind" (or of a group of minds) and to be absorbed in making, manifesting, or reacting to a series of signs is to be absorbed in "being a mind". "[...] all thinking is dialogic in form" [8, 6.338], both at the intrasubjective[7] and intersubjective level, so that we see ourselves exactly as others see us, or see them exactly as they see themselves, and we see ourselves through our own speech and other interpretable behaviors, just others see us and themselves in the same way, in the commonality of the whole process [32, p. 10].

As I will better explain later on in the following sections, in this perspective minds are material like brains, in so far as they consist in intertwined internal and external semiotic processes: "[...] the psychologists undertake to locate various mental powers in the brain; and above all consider it as quite certain that the faculty of language resides in a certain lobe; but I believe it comes decidedly nearer the truth (though not really true) that language resides in the tongue. In my opinion it is much more true that the thoughts of a living writer are in any printed copy of his book than they are in his brain" [8, 7.364].

2.3.1 Man is an External Sign

Peirce's semiotic motto "man is an external sign" is very clear about the materiality of mind and about the fact that the conscious self[8] is a cluster actively embodied of flowing intelligible signs:

> It is sufficient to say that there is no element whatever of man's consciousness which has not something corresponding to it in the word; and the reason is obvious. It is that the word or sign which man uses *is* the man himself. For, as the fact that every thought is a sign, taken in conjunction with the fact that life is a train of thoughts, proves that man is a sign; so, that every thought is an *external sign*, proves that man is an external sign. That is to say, the man and the *external sign* are identical, in the same *sense* in which the words *homo* and *man* are identical. Thus my language is the sum total of myself; for the man is the thought [8, 5.314].

It is by way of signs that we ourselves *are* semiotic processes – for example a more or less coherent cluster of narratives. If all thinking is in signs it is not true that thoughts are in us because we are in thoughts.

[7] "One's thoughts are what he is 'saying to himself', that is saying to that other self that is just coming to life in the flow of time. When one reasons, it that critical self that one is trying to persuade: and all thought whatsoever is a sign, and is mostly in the nature of language" [8, 5.421].

[8] Consciousness arises as "a sort of public spirit among the nerve cells" [8, 1.354].

I think it is at this point clearer what I meant in section 2.1.2, when I explained the concept of model-based abduction and said, adopting a Peircian perspective, that all thinking is in signs, and signs can be icons, indices, or symbols and that, moreover, all *inference* is a form of sign activity, where the word sign includes feeling, image, conception, and other representation. The model-based aspects of human cognition are central, given the central role played for example by signs like images and feeling in the inferential activity "[. . .] man is a sign developing according to the laws of inference. [. . .] the entire phenomenal manifestation of mind is a sign resulting from inference" [8, 5.312 and 5.313].

Moreover, the "person-sign" is future-conditional, that is not fully formed in the present but depending on the future destiny of the concrete semiotic activity (future thoughts and experience of the community) in which she will be involved. If Peirce maintains that when we think we appear as a sign [8, 5.283] and, moreover, that everything is present to us is a phenomenal manifestation of ourselves, then feelings, images, diagrams, conceptions, schemata, and other representations are phenomenal manifestations that become available for interpretations and thus are guiding our actions in a positive or negative way. They become *signs* when we think and interpret them. It is well-known that for Peirce all semiotic experience – and thus abduction - is also providing a guide for action. Indeed the whole function of thought is to produce habits of action.[9]

In the following sections I will describe how the interplay of signs, objects, and interpretations is working in important aspects of abductive reasoning. Of course model-based cognition acquires its peculiar creative relevance when embedded in abductive processes. I will show some examples of model-based inferences. It is well known the importance Peirce ascribed to diagrammatic thinking (a kind of iconic thinking), as shown by his discovery of the powerful system of predicate logic based on diagrams or "existential graphs". As we have already stressed, Peirce considers inferential any cognitive activity whatever, not only conscious abstract thought; he also includes perceptual knowledge and subconscious cognitive activity. For instance in subconscious mental activities visual representations play an immediate role [34].

Many commentators always criticized the Peircian ambiguity in treating abduction in the same time as inference and perception. It is important to clarify this problem, because perception and imagery are kinds of that model-based cognition which we are exploiting to explain abduction: in [7] I conclude we can render consistent the two views, beyond Peirce, but perhaps also within the Peircian texts, taking advantage of the concept of *multimodal* abduction, which depicts hybrid aspects of abductive reasoning.

Thagard [35, 36] observes, that abductive inference can be visual as well as verbal, and consequently acknowledges the sentential, model–based, and manipulative nature of abduction I have illustrated above. Moreover, both data and hypotheses can be visually represented:

[9] On this issue cf. for example the contributions contained in recent special issue of the journal *Semiotica* devoted to abduction [34].

> For example, when I see a scratch along the side of my car, I can generate the mental image of grocery cart sliding into the car and producing the scratch. In this case both the target (the scratch) and the hypothesis (the collision) are visually represented. [...] It is an interesting question whether hypotheses can be represented using all sensory modalities. For vision the answer is obvious, as images and diagrams can clearly be used to represent events and structures that have causal effects [36].

Indeed hypotheses can be also represented using other sensory modalities:

> [...] I may recoil because something I touch feels slimy, or jump because of a loud noise, or frown because of a rotten smell, or gag because something tastes too salty. Hence in explaining my own behavior my mental image of the full range of examples of sensory experiences may have causal significance. Applying such explanations of the behavior of others requires projecting onto them the possession of sensory experiences that I think are like the ones that I have in similar situations. [...] Empathy works the same way, when I explain people's behavior in a particular situation by inferring that they are having the same kind of emotional experience that I have in similar situations [36].

Thagard illustrates the case in which a professor with a recently rejected manuscript is frowning: another colleagues can empathizes by remembering how annoying she felt in the same circumstances, projecting a mental image onto the colleague that is a non-verbal representation able to explain the frown. Of course a verbal explanation can be added, but this just complements the empathetic one. It is in this sense that Thagard concludes that abduction can be fully multimodal, in that both data and hypotheses can have a full range of verbal and sensory representations. Some basic aspects of this constitutive hybrid (and thus intrinsically multidisciplinary) nature of abduction – involving words, sights, images, smells, etc. but also kinesthetic experiences and other feelings such as pain – will be investigated in the following sections.

2.4 Constructing and Communicating Meaning through Mimetic and Creative External Objects

2.4.1 Constructing Meaning through Manipulative Abduction

Manipulative abduction occurs when many external things, usually inert from the semiotic (and so for example epistemic) point of view, can be transformed into what I have called, in the case of scientific reasoning, "epistemic mediators" [20] that give rise to new signs, new chances for interpretations, and new interpretations.

We can cognitively account for this process of externalization[10] taking advantage of the concept of *manipulative* abduction (cf. Figure 2.3). It happens when we

[10] A significant contribution to the comprehension of this process in terms of the so–called "disembodiment of the mind" derives from some studies in the field of cognitive

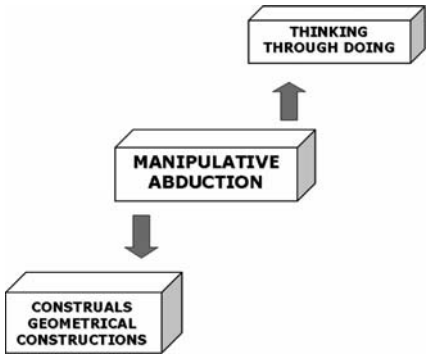

Fig. 2.3. Manipulative abduction.

are thinking *through* doing and not only, in a pragmatic sense, about doing. It happens, for instance, when we are creating geometry constructing and manipulating an external suitably realized icon like a triangle looking for new meaningful features of it, like in the case given by Kant in the "Transcendental Doctrine of Method" ([21] and the following section). It refers to an extra–theoretical behavior that aims at creating communicable accounts of new experiences to integrate them into previously existing systems of experimental and linguistic (semantic) practices.

Gooding [10] refers to this kind of concrete manipulative reasoning when he illustrates the role in science of the so-called "construals" that embody tacit inferences in procedures that are often apparatus and machine based. The embodiment is of course an expert manipulation of meaningful semiotic objects in a highly constrained experimental environment, and is directed by abductive movements that imply the strategic application of old and new *templates* of behavior mainly connected with extra-rational components, for instance emotional, esthetical, ethical, and economic.

The hypothetical character of construals is clear: they can be developed to examine or discard further chances, they are provisional creative organization of experience and some of them become in their turn hypothetical *interpretations* of experience, that is more theory-oriented, their reference/meaning is gradually stabilized in terms of established observational practices. Step by step the new interpretation - that at the beginning is completely "practice-laden" - relates to more "theoretical" modes of understanding (narrative, visual, diagrammatic, symbolic, conceptual, simulative), closer to the constructive effects of theoretical abduction. When the reference/meaning is stabilized the effects of incommensurability with other established observations can become evident. But it is just the construal of certain phenomena that can be shared by the sustainers of rival theories. Gooding [10] shows how Davy and Faraday could see the same attractive and repulsive actions at work in the phenomena they respectively produced; their discourse and practice as to the role of their

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paleoanthropology that describe various related aspects of the birth of the material "culture". In [7] I have illustrated this issue relating it to the Turing ideas on "unorganized" and "organized" brains.

construals of phenomena clearly demonstrate they did not inhabit different, incommensurable worlds in some cases. Moreover, the experience is constructed, reconstructed, and distributed across a social network of negotiations among the different scientists by means of construals.

It is difficult to establish a list of invariant behaviors that are able to describe manipulative abduction in science. As illustrated above, certainly the expert manipulation of objects in a highly semiotically constrained experimental environment implies the application of old and new *templates* of behavior that exhibit some regularities. The activity of building construals is highly conjectural and not immediately explanatory: these templates are hypotheses of behavior (creative or already cognitively present in the scientist's mind-body system, and sometimes already applied) that abductively enable a kind of epistemic "doing": for example it allows us to find epistemica chances which in some cases can reflect concrete risks in the studied situation. Hence, some templates of action and manipulation can be *selected* in the set of the ones available and pre-stored, others have to be *created* for the first time to perform the most interesting creative cognitive accomplishments of manipulative abduction.

Moreover, I think that a better understanding of manipulative abduction at the level of scientific experiment could improve our knowledge of induction, and its distinction from abduction: manipulative abduction could be considered as a kind of basis for further meaningful inductive generalizations. Different generated construals can give rise to different inductive generalizations.

Some common features of these tacit templates that enable us to manipulate things and experiments in science to favor meaning formation are related to: 1. sensibility towards the aspects of the phenomenon which can be regarded as *curious* or *anomalous*; manipulations have to be able to introduce potential inconsistencies in the received knowledge (Oersted's report of his well-known experiment about electromagnetism is devoted to describe some anomalous aspects that did not depend on any particular theory of the nature of electricity and magnetism; Ampère's construal of experiment on electromagnetism - exploiting an artifactual apparatus to produce a static equilibrium of a suspended helix that clearly shows the role of the "unexpected"); 2. preliminary sensibility towards the *dynamical* character of the phenomenon, and not to entities and their properties, common aim of manipulations is to practically reorder the dynamic sequence of events in a static spatial one that should promote a subsequent bird's-eye view (narrative or visual-diagrammatic); 3. referral to experimental manipulations that exploit *artificial apparatus* to free new possibly stable and repeatable sources of information about hidden knowledge and constraints (Davy well-known set-up in terms of an artifactual tower of needles showed that magnetization was related to orientation and does not require physical contact). Of course this information is not artificially made by us: the fact that phenomena are made and manipulated does not render them to be idealistically and subjectively determined; 4. various contingent ways of epistemic acting: *looking* from different perspectives, *checking* the different information available, *comparing* subsequent events, *choosing*, *discarding*, *imaging* further manipulations, *re-ordering*

and *changing relationships* in the world by implicitly *evaluating* the usefulness of a new order (for instance, to help memory).

From the general point of view of everyday situations manipulative abductive reasoning exhibits other very interesting templates: 5. action elaborates a *simplification* of the reasoning task and a redistribution of effort across time when we "need to manipulate concrete things in order to understand structures which are otherwise too abstract" [11], or when we are in presence of *redundant* and unmanageable information; 6. action can be useful in presence of *incomplete* or *inconsistent* information - not only from the "perceptual" point of view - or of a diminished capacity to act upon the world: it is used to get more data to restore coherence and to improve deficient knowledge; 7. action as a *control of sense data* illustrates how we can change the position of our body (and/or of the external objects) and how to exploit various kinds of prostheses (Galileo's telescope, technological instruments and interfaces) to get various new kinds of stimulation: action provides some tactile and visual information (e.g., in surgery), otherwise unavailable; 8. action enables us to build *external artifactual models* of task mechanisms instead of the corresponding internal ones, that are adequate to adapt the environment to the agent's needs: experimental manipulations exploit *artificial apparatus* to free new possible stable and repeatable sources of information about hidden knowledge and constraints.

The whole activity of manipulation is devoted to build various external *epistemic mediators*[11] that function as versatile semiotic tools able to provide an enormous new source of data, information, and knowledge. Therefore, manipulative abduction represents a kind of redistribution of the epistemic and cognitive effort to manage objects and information that cannot be immediately represented or found internally (for example exploiting the resources of visual imagery).[12]

If we see scientific discovery like a kind of opportunistic ability of integrating information from many kinds of simultaneous constraints to produce explanatory hypotheses that account for them all, then manipulative abduction will play the role of eliciting possible hidden constraints by building external suitable experimental structures.

2.4.2 Manipulating and Communicating Meanings through External Semiotic Anchors

If the structures of the environment play such an important role in shaping our semiotic representations and, hence, our cognitive processes, we can expect that physical manipulations of the environment receive a great cognitive relevance.

Several authors have pointed out the role that physical actions can have at a cognitive level. In this sense Kirsh and Maglio [16] distinguish actions into two categories,

[11] I derive this expression from the cognitive anthropologist Hutchins, that coins the expression "mediating structure" to refer to various external tools that can be built to cognitively help the activity of navigating in modern but also in "primitive" settings [6, 15].

[12] It is difficult to preserve precise spatial relationships using mental imagery, especially when one set of them has to be moved relative to another.

namely *pragmatic actions* and *epistemic actions*. Pragmatic actions are the actions that an agent performs in the environment in order to bring itself physically closer to a goal. In this case the action modifies the environment so that the latter acquires a configuration that helps the agent to reach a goal which is understood as physical, that is, as a desired state of affairs. Epistemic actions are the actions that an agent performs in a semiotic environment in order to discharge the mind of a cognitive load or to extract information that is hidden or that would be very hard to obtain only by internal computation.

In this section I want to focus specifically on the relationship that can exist between manipulations of the environment and representations. In particular, I want to examine whether external manipulations can be considered as means to construct external representations.

If a manipulative action performed upon the environment is devoted to create a configuration of signs that carries relevant information, that action will well be able to be considered as a cognitive semiotic process and the configuration of elements it creates will well be able to be considered an external representation. In this case, we can really speak of an embodied cognitive process in which an action constructs an external representation by means of manipulation. We define *cognitive manipulating* as any manipulation of the environment devoted to construct external configurations that can count as representations.

An example of cognitive manipulating is use of diagrams in mathematical reasoning. In this case diagrams carry relevant semiotic information about the internal angles of a triangle "anchoring" new meanings.

The entire process through which an agent arrives at a physical action that can count as cognitive manipulating can be understood by means of the concept of manipulative abduction [20]. Manipulative abduction is a specific case of cognitive manipulating in which an agent, when faced with an external situation from which it is hard or impossible to extract new meaningful features of an object, selects or creates an action that structures the environment in such a way that it gives information which would be otherwise unavailable and which is used specifically to infer explanatory hypotheses.

In this way the semiotic result is achieved on *external* representations used in lieu of the internal ones. Here action performs an *epistemic* and not a merely performatory role, for example relevant to abductive reasoning.

2.4.3 Communication and Semiosis through Re-Embodiment

Some interesting semiotic aspects of the above illustrated communicative process can be nicely analyzed. Imagine that a suitable *fixed internal record* exists – deriving from the cognitive exploitation of the previous suitable interplay with *external structures* - at the level of neural activation and that for instance it embeds an abstract concept endowed with all its features, for example the concept of triangle. Now, the human agent, via neural mechanisms and bodily actions, can "re-embody" that concept by making an external perceivable *sign*, for instance available to the attention (and so potentially communicable) of other human or animal senses and brains. For

instance that human agent can use what in semiotics is called a *symbol* (with its conventional character: *ABC*, for example), but also an *icon* of relations (a suitable diagram of a triangle), or a *hybrid representation* that will take advantage of both. In Peircian terms:

> A representation of an idea is nothing but a sign that calls up another idea. When one mind desires to communicate an idea to another, he embodies his idea by making an outward perceptible image which directly calls up a like idea; and another mind perceiving that image gets a like idea. Two persons may agree upon a conventional sign which shall call up to them an idea it would not call up to anybody else. But in framing the convention they must have resorted to the primitive diagrammatic method of embodying the idea in an outward form, a picture. Remembering what likeness consists in, namely, in the natural attraction of ideas apart from habitual outward associations, I call those signs which stand for their likeness to them *icons*. Accordingly, I say that the only way of directly communicating an idea is by mean of an icon; and every indirect method of communicating an idea must depend for its establishment upon the use of an icon [19, 787, 26–28].[13]

It is well-known that for Peirce every picture is a icon and thus every diagram, even if it lacks a sensuous similarity with the object, but just exhibits an analogy between the relations of the part of it and of the object:

> Particularly deserving of notice are icons in which the likeness is aided by conventional rules. Thus, an algebraic formula is an icon, rendered such by the rules of commutation, association, and distribution of the symbols; that it might as well, or better, be regarded as a compound conventional sign. It may seem at first glance that it is an arbitrary classification to call an algebraic expression an icon; that it might as well, or better, be regarded as a compound of conventional sign. But it is not so. For a great distinguishing property of the icon is that by direct observation of it other truths concerning its object can de discovered than those which suffice to determine its construction. Thus, by means of two photographs a map can be drawn, etc. Given a conventional or other general sign of an object, to deduce any other truth than which it explicitly signifies, it is necessary, in all cases, to replace that sign by an icon. This capacity of revealing unexpected truth is precisely that wherein the utility of algebraic formulae consists, so that the icon in character is the prevailing one [19, 787, CSP 26–28].

Stressing the role of iconic dimensions of semiosis[14] in the meantime celebrates the virtues in communication of analogy, as a kind of "association by resemblance",

[13] We have to note that for Peirce an idea "[...] is not properly a conception, because a *conception* is not an idea at all, but a *habit*. But the repeated occurrence of a general idea and the experience of its *utility*, results in the formation or strengthening of that habit which is the conception" [8, 7.498].

[14] We have to remember that in this perspective any proposition is a diagram as well, because it represents a certain relation of symbols and indices.

as contrasted to "association by contiguity". The emphasis on iconic and analogical aspects of both everyday and scientific reasoning clearly favors the role of interdisciplinarity in communication and production of multiple clusters of data.

Human beings delegate cognitive (for example communicative and epistemic) features to external representations through semiotic attributions because for example in many problem solving situations the internal computation would be impossible or it would involve a very great effort because of human mind's limited capacity. First a kind of "alienation" is performed, second a recapitulation is accomplished at the neuronal level by re-representing internally that which was "discovered" outside. Consequently only later on we perform cognitive operations on the structure of data that synaptic patterns have "picked up" in an analogical way from the environment. We can maintain that internal representations used in cognitive processes like many events of *meaning creation* and *communication* have a deep origin in the experience lived in the semiotic environment.

I already illustrated in section 2.2 that I think there are two kinds of artifacts that play the role of *external objects* (representations) active in this process of externalization of the mind: *creative* and *mimetic*. Mimetic external representations mirror concepts and problems that are already represented in the brain and need to be enhanced, solved, further complicated, etc. so they sometimes can creatively give rise to new concepts and meanings. Hence, interesting (and new) information and knowledge packages are generated and stored over there in the external human niches, in various supports more or less accessible that can be picked up in further data communication and chance/risk discovering processes.

Following my perspective it is at this point evident that the "mind" transcends the boundary of the individual and includes parts of that individual's environment. It is in this sense that the mind is semiotic and artificial.

2.4.4 Delegated and Intrinsic Constraints in External Agents

We have said that through the cognitive interplay with external representations the human agent is able to pick up and use what suggested by the constraints and features intrinsic to their external materiality and to their relative established conventionality: data, artificial languages, proofs, examples, etc. At the beginning of this kind of process the human agent embodies a sign in the external world that for example in classical geometry is an icon endowed with "intentional" delegated cognitive conventional and public features – meanings - that resort to some already known properties of the Euclidean geometry: a certain language and a certain notation, the definition of a triangle, the properties of parallel lines that also hold in case of new elements and "auxiliary" constructions obtained through manipulation, etc. Then she looks, through diagram manipulations, for possible necessary consequences that occur over there, in the diagram/icon and that obey both

- the conventional *delegated* properties and
- the properties *intrinsic* to the materiality of the model.

This external model is a kind of autonomous cognitive *agent* offered to new interpretations of the problem/object in question. The model can be picked up later and acknowledged by the human agent through fixation of a new neural configuration – a new "thought". This operation can be imagined as acting in other epistemic settings, for example in manipulations of multiple data of a specific multidisciplinary field, as a way for extracting/discovering new chances/risks implicity embedded in the case/circumstances under analysis.

The distinction above between delegated and intrinsic and immanent properties is also clear if we adopt the Peircian semiotic perspective. Peirce – speaking about the case of syllogistic logic, and not of geometry or algebra - deals with this problem by making an important distinction between what is going on in the brain of the logical human agent and the autonomous power of the chosen external system of representation or diagrammatization [37]. The presence of this "autonomous power" explains why I attribute to the system of representation a status of cognitive agency similar to the one of a human person, even if of course lacking aspects like direct intention and responsibility. Imagine for instance, the powerful autonomous agency which is represented by a Practical Universal Turing Machine (a PC with its software). In the case of diagrams, Peirce says, it makes use

> [...] of a particular system of symbols - a perfectly regular and very limited kind of language. It may be a part of a logician's duty to show how ordinary ways of speaking and of thinking are to be translated into that symbolism of formal logic; but it is no part of syllogistic itself. Logical principles of inference are merely rules for the illative transformation of the symbols of the particular system employed. If the system is essentially changed, they will be quite different [8, 2.599].

Of course the argumentation above also holds for the case of iconic geometric representation and can be extended in many other epistemic setting where for example the external support is a computational tool. This distinction integrates the one I have introduced above in the two levels of representations, and in some sense blurs it by showing how the *hybrid* character of the system composed by the two levels themselves, where the whole package of sensorial and kinesthetic abilities are involved.

The construction of the diagram also depends on those delegated semiotic properties that are embedded in what Peirce calls "precept" as he says in the passage we have already quoted above and not only on the constraints expressed by the materiality of the model itself.[15] A diagram has various semiotic properties just like a computation tool presents a lot of constraints but also of knowledge chances, when suitably exploited in the external/internal interplay I have described in section 2.2.

Pickering [39] depicts the role of some externalities (representations, artifacts, tools, etc.) in terms of a kind of non-human agency that interactively stabilizes with

[15] It is worth noting that this process is obviously completely related to the Peircian idea of pragmatism [38], that he simply considers "the experimental method" which is the procedure of all science.

human agency in a dialectic of resistance and accommodation [39, p. 17 and p. 22]. The two agencies, for example in scientific reasoning, originate a co-production of cognition the results of which cannot be presented and identified in advance: the outcome of the co-production is intrinsically "unpredictable". Latour's notions of the de-humanizing effect of technologies are based on the so-called "actor network theory",[16] which also stresses the semiotic role of externalities like the so-called non human agents. The actor network theory basically maintains that we should think of science, technology, and society as a field of human and non-human (material) agency. Human and non-human agents are associated with one another in networks, and they evolve together within these networks. Because the two aspects are equally important, neither can be reduced to the other: "An actor network is simultaneously an actor whose activity is networking heterogeneous elements and a network that is able to redefine and transform what is it made of [. . .]. The actor network is reducible neither to an actor alone nor to a network" [41, p. 93].

The operation on a diagram has reduced complexity enabling concentration on essential relations and has revealed new data. Moreover, through manipulations of the diagram new perspectives are offered to the observation, or interesting anomalies with respect the internal expectations are discovered. In the case of mathematicians, Peirce maintains, the diagram "puts before him an icon by the observation of which he detects relations between parts of the diagram other than those which were used in its construction" [46, III, p. 749]: "unnoticed and hidden relations among the parts" are discovered [8, 3.363]. This activity is a kind of "thinking through doing": "In geometry, subsidiary lines are drawn. In algebra permissible transformations are made. Thereupon, the faculty of observation is called into play. [. . .] Theorematic reasoning invariably depends upon experimentation with individual schemata" [8, 4.233].

We have said that firstly the human agent embodies a sign in the external world that is in this geometrical case an icon endowed with "intentional" delegated cognitive conventional and public features – meanings - that resort to some already known properties of the Euclidean geometry: these features can be considered a kind of immanent rationality and regularity [38] that establishes a disciplinary field to envisage conclusions.[17] The system remains relative to the chosen conventional framework. They are real as long as there is no serious doubt in their adequacy: "The 'real,' for Peirce, is part of an evolutionary process and while 'pragmatic belief' and unconscious habits might be doubled from a scientific point a view, such a science might also formulate serious doubts in its own representational systems" [38, p. 295].

Let us imagine we choose a different representational system still exploiting material and external diagrams. Through the manipulation of the new symbols and diagrams we expect very different conclusions. An example is the one of the non-

[16] This theory has been proposed by Callon, Latour himself, and Law [40–45].

[17] Paavola, Hakkarainen, and Sintonen [47] consider the interplay between internal and external aspects of abductive reasoning in the framework of the interrogative model of the so-called "explanation-seeking why-questions". They emphasize the interaction with the "environment" and show the importance of the heuristic strategies and of their trialogic nature (inquirer and fellow inquirers, object of inquiry, mediating artefacts and processes), also taking advantage of Davidson's ideas concerning triangulation.

Euclidean discoveries. In Euclidean geometry, by adopting the postulate of parallels we necessarily arrive to the ineluctable conclusion that the sum of internal angles of a triangle is 180°, but this does not occur in the case of the non-Euclidean geometry where a different selected representational system - that still uses Euclidean icons - determines quite different possibilities of constructions, and thus different results from iconic experimenting.[18]

2.5 Conclusion

The main thesis of this paper is that the process of externalization of mind is a significant cognitive perspective able to unveil some basic features of abductive reasoning in both everyday and epistemic settings. Its fertility in explaining the semiotic communicative interplay between internal and external levels of cognition is evident and stressed its obvious interdisciplinary character. I maintain that various aspects of creative meaning formation and communication could take advantage of the research on this interplay: for instance study on external mediators can provide a better understanding of the processes of explanation and discovery (an chance discovery) in science and in some areas of artificial intelligence related to mechanizing discovery processes, where the aim at discovering chances and risks in the related studied situation is central.[19]

The cognitive referral to the central role of the relation between meaningful behavior and dynamical interactions with the environment becomes critical to the problem of meaning formation and communication. The perspective above, resorting to the exploitation of a very interdisciplinary interplay will further shed light on how concrete manipulations of external objects influence the abductive generation of hypotheses and so on the characters of what I call manipulative abduction showing how we can find methods of constructivity – and their computational counterparts – in scientific and everyday reasoning based on external models and "epistemic mediators" [50], as tools that can enhance in many ways risk/chance construction or extraction/elicitation.

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[18] I have illustrated this problem in detail in [48].

[19] On the recent achievements in the area of the machine discovery simulations of model-based creative tasks cf. [49].

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