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*F.T. Arecchi*

# Complexity and adaptation: a strategy common to scientific modeling and perception

**Abstract**
Scientific investigation displays close similarities with a perceptual task. In both cases, categories already stored in a semantic memory cannot be assumed as working hypotheses for an interpretation, but they must be matched with novel information, not deducible from the starting data set. The irruption of non trivial novelty is the mark of complexity as opposed to the simplicity of what can be deduced by an algorithmic procedure. The adaptive strategies, whereby we cope with complexity both in scientific modeling and in perception, represent a clear demonstration of the objective character of reality, which is not a mental construction.

## 1. Introduction

A widespread attitude within the cognitive science community consists in reducing the mind-body problem to the dichotomy between software and hardware in a computer, that is, between the programs and the physical machinery which carries them on. Hence, the fact that a program can be executed by different physical machineries gives rise to the misconception of a disembodied thought, as Descartes' "res cogitans".

Regarding the res cogitans as an agent who categorizes the sense impressions and organizes them as thoughts, we realize that the knowledge problem reduces to the correspondence between two Cantor sets, that of the worldly events ("res extensa") and that of our mental schemes. As a result of this attitude three consequences emerge, namely,

i) knowledge is not the creation of novelty, but just the correspondence between two sets established "ab aeterno"; God reduces to an inspector granting the good ordering between the two sets, such is indeed the "Deus sive Natura" of Spinoza;

ii) the classical truth criterion as "adaequatio intellectus et rei" is replaced by the Cartesian criterion of "clear and distinct ideas", that is, by a requirement of self consistency of our mental procedures;

iii) the AI (Artificial Intelligence) proposal of a machine equipped with a sufficient number of "subroutines" in its archives in order to cope with whatever problem, is a presumption of solipsism; in Hofstadter's, "Gödel, Escher and Bach: an eternal golden braid", (Hofstadter) the golden braid is the entangled set of routines which refer to each other in a self consistent way.

In a similar way, a scientific program is currently seen as a two phase task. In the first phase, one gathers relevant features via measuring apparatuses; the features are then organized into an axiom set. The second phase consists in deducing all consequences. The deduction parallels the deterministic evolution of the world. If the first phase has captured the relevant features, then the second phase yields prediction of all future events.

Both approaches, that is, the cognitive program and the scientific modeling, fail whenever complexity occurs. We loosely denote by complexity the emergence of events not deducible from our initial data set, be it our personal set of sensations or the body of measurements on which science is built.

The aim of this paper is to show that adaptation is crucial to provide novelty in knowledge. Adaptation means considering new features whenever necessary, not just selecting a different sub-routine which is already part of the "golden braid".

The neuro-physiological counterpart is called "feature binding" (Van der Malsburg, Singer and Gray). It consists in the synchronization of the electrical spikes travelling in the neurons of different brain areas which cooperate to the same global perception, and such a synchronization implies the re-adjustment of the individual neuron thresholds. This is done through signals flowing top-down from the semantic memory to the higher cortical stages in order to match inputs arriving bottom-up from the peripheral cortical stages directly connected to the sensor terminals. If the matching is not reached, this denotes a novel experience which must be categorized as a new feature previously absent in the semantic memory. Besides being a sound conjecture called ART=Adaptive Resonance Theory (Grossberg), this type of learning has indirect confirmation in the experimental evidence of the anatomical growth of new synaptic connections even in aged individuals.

In Sec. 2 and 3 I show how the Cartesian cut between res cogitans and extensa is equivalent to a simplified model of the knowledge procedure which would then be unable to cope with complex situations. To deal with complexity, any cognitive agent recurs to adaptive strategies which uncover an ontological foundation of our knowledge acts

(Sec. 4). In Sec. 5, I review the recent approaches to visual perception, in terms of "feature binding" and ART, which are the physiological correlate of the adaptive strategy discussed in Sec. 4 for model building. Combining Secs. 4 and 5 we see that both cognitive endeavors of a human being, namely, the extraction of coherent perceptions out of sense stimuli and the successive organization of perceptions into models of reality, result from a trade off between categories already stored in a semantic memory and the continuous modifications induced by the in-flow of novel features.

In Sec. 6 we speak of an open science, that is, a science not closed in a self-referential way as Hofstadter's machine. This aperture implies the reality of universals.

Within a reductionistic framework, the collective terms, such as "wood" to denote many close by trees or "flock" to denote many animals with correlated behaviors, seem purely linguistic connotations. However the mutual relations among individuals create a novel unity which would not exist if we were just dealing with sets of uncorrelated objects. I here report some statements about this question (Armstrong).

It is argued, first, that there are universals, both monadic and polyadic, that is, properties and relations, which exist independently of the classifying mind. Realist is thus accepted, nominalism rejected. Second, it is argued that no monadic universal is found except as a property of some particular, and no polyadic universal except as a relation holding between particulars. Transcendent or Platonic realism is thus rejected. Third, it is argued that what universals there are is not to be determined simply by considering what predicates can be applied to particulars. Instead, it is the task of total science, conceived of as total enquiry, to determine what universals there are. The view defended is therefore a scientific realism about universals. It might also be called a posteriori realism……. Contemporary philosophy recognizes two main lines of argument for the existence of objective universals. The first is, or is a descendant of, Plato's One over Many argument. Its premiss is that many different particulars can all have what appears to be the same nature. In the terms used by C.S. Peirce, different tokens may all be of the same type. The conclusion of the argument is simply that in general this appearance cannot be explained away, but must be accepted.….

….with the exception of a suggestive paper by Hilary Putnam (1970: On Properties, in "Essays in Honour of C.G. Hampel", Reprinted in Philosophical Papers, Vol. 1, Cambridge University Press) contemporary philosophers, at least, have largely ignored the possibility of developing a theory of objective universals, where the particular universals admitted are determined on the basis of scientific rather than semantic considerations. It might perhaps be argued that Plato in his later works, Aristotle and the Scholastic Realists were ahead of contemporary philosophy in this matter, although handicapped by the relative backwardness of the science and the scientific methodology of their day. My contention is that, by accepting this a posteriori Realism, the theory of universals, arguably the central problem of ontology, can be placed on a securer and more intelligible foundation that anything previously available. In particular, such a doctrine makes possible the reconciliation of an empiricist epistemology, which I wish to retain, with ontological realism about universals.

Recovering the ontological value of the universals implies recognizing a hierarchy of different natures, each one characterized by proper operations.

The AI presumption of reducing a human being to a hardware, that is, a collection of components, plus a software called "mind" (such is the so-called "functionalism") is untenable already within the limited framework of a purely phenomenological investigation. Furthermore, the recovery of the ontological significance of the universals implies that a purely scientific description can answer the "hows" but it leaves open the "why" questions which are by no means irrelevant, but which lie beyond the scientific explanation and represent its same foundation. All this should result from the following Sections dealing with the problem of complexity.

## 2. The Cartesian schism and modern science

The Cartesian split, or "schism", between res cogitans and res extensa, has been the source of an automatism in the scientific endeavor which is still matter of epistemological debate. This is shown with reference to Fig. 1. Let us call R the reality, S the agent who formulates statements about reality and M the collection of our senses as well as those extensions of our senses which are our measurement apparatuses. Within the Cartesian split, M is part of res extensa, and res cogitans S receives passively the signals coded by M. S is like the film of a fixed focus camera, recording the impressions without contributing to their build up (solid line from M to S).

At the same time of the Cartesian schism, Galilei formulated his scientific program as "not attempting" to grasp the natures but just sticking to the quantitative affections" (Galilei) that is, reducing our knowledge of the world to a limited number of connotations, provided by different measuring apparatuses, each one calibrated on a proper scale. Each connotation is then coded in a number on a suitable scale. On this epistemological line, Herbert Spencer identified science as the collection of our measuring apparatuses (Cassirer).

As a result of this attitude a key role has been attributed to an expert system, that is, to a computer equipped with an archive built by a collection of different measurements. The hope that an expert system could replace human investigators in medical diagnosis or in economic forecasting is based on the Cartesian presumption that man is reducible

to a group of apparatuses M plus a computer fed by the M outputs in order to start programs based on algorithms which represent models of the world.

Within this horizon, the scientific program consists in characterizing an event by a number n of measurements via n apparatuses M. The ordered collection of the n numbers represent the state of the system as a point in n- dimensional space. Therefore, a dynamical evolution is the collection of points at different times, which makes a line in such a space. The aim of scientific discovery reduces to establish which are the n essential dimensions. These are called the "degrees of freedom" of the system under observation; based on Occam razor, we must not overcome n. Powerful elaboration methods, called "nonlinear data analysis" have been developed (Abarbanel et al.) Since in nonlinear dynamics all the different degrees of freedom are tightly entangled, it is not necessary to observe all of them; it is sufficient to sample just one in course of time and then embed the corresponding one dimensional string of temporal data into spaces of increasing dimensions, 2,3,4 etc. by suitable mathematical techniques. As one overcomes n, the data analysis provides a check of redundancy, thus blocking the further growth of the dimension number and avoiding to violate Occam criterion.

Until science had provided univocal results, it was possible, like Galileo, to believe that science was reading in the book of nature discovering the same worlds which were written in it by God. The self limitation to quantitative features endowed science with an insight unknown to philosophy. The self limitation represented a creative procedure compressing the relevant information into compact formulas or laws, and disregarding those features which were irrelevant for the further evolution. This way science seemed to assure a reliable prediction of the future, and its language seemed to eliminate the ambiguities of the ordinary language. In other words science was able to isolate what was relevant in view of the world evolution. Whence the belief that any sensible discourse had to be formulated within the rules of the scientific language, avoiding the non sense of the ordinary language. This belief, initially expressed by Wittgenstein as aphorisms, was later formalized by the Wiener Kreis as a "logical construction of the world", based on a starting group of concepts and verifiable relations (the axioms) and on the further deduction of all their possible consequences. Any problem outside this scheme was considered irrelevant (logical atheism).

However in these recent years, the attempts of scientific description of complex systems have unveiled situations not considered in the first three centuries of science. Precisely, a correct syntactic procedure does not generally lead to unique final situation, but to a large number of alternative situations with comparable probabilities of occurrence. On the contrary, the experimental observation shows that only one of the predicted outcomes has in fact realized. This gives rise to a conflict between syntax and semantics, between truth and certitude. The initial axiom set making up the scientific model must be integrated with elements of reality not included (not deducible from) that set.

**3. <u>Complexity</u> (Arecchi, 1996, 1999a)**

The logical construction of the world starting from its elements leads to simple results only in particular cases. In general the procedure yields a tree of possible solutions with many branches, the number of which increases exponentially with the size of the system, that is, with the number of the elementary components. Characterizing all possible final states of such a dynamics, would be an "intractable" task, since the corresponding computation time is generally longer than the effective time necessary to the piece of world under investigation to reach a final state. In such a case the most sensible thing is to sit down and wait until things happen, giving up with predictability. Of course, this would be highly unsatisfactory since it would mean recognizing the failure of the scientific program.

Considering the computation time shifts the emphasis from the "problem solving" to the "decision making". Ideally, one could solve a problem in an extremely long time. But in real life, every agent is embedded in a changing world and his vital decisions, such as adaptation to the environment, defence from a danger, classification of the phenomena, must be taken while the world is changing, thus they are relevant only if the decision time is shorter than the correlation time of the outside connotations.

Before offering a remedy, that I will call "adaptive strategy", and which is equivalent to re-introducing the classical criterion of truth as "adaequatio", let me explain how the problem of complexity has risen within the scientific program.

The words of the ordinary language are polysemous since they do not refer to isolated objects but to objects embedded in a context. No object can be isolated from its context, since its interaction with the environment contributes to assigning different nuances. If we call "event" an object plus its context, the same word denotes, in a rather ambiguous way, a whole collection of events. This collection represents the semantic space of that word. In a historical dictionary the set of all possible meanings is truncated to a finite small number of connotations, that is, those used by the Authors in the literature of that language.

A text, seen as a flow of words connected by grammatical rules, appears as a wide riverbed which joins different semantic spaces. Within it, one can cut different interpretations. As well known, no text can be read in a univocal way and in order to reduce the range of possible interpretations, we need to consider elements outside the text. A self consistent reading of a text, whereby each word is specified by its correlation with the other ones, it rather illusory.

We call complexity the fact that the global information (I here use information in the common sense without referring to a technical meaning) is not the sum of each information that the dictionary attributes to each word; in fact there is a mutual information emerging from the structure of the literary text and from the semantic memory recalled by the used terms.

All the above ambiguities seemed overcome by Galileo's program. Limiting the attention to quantities is equivalent to applying a measuring apparatus M with a protocol of use. The output number from M is a suitable coding of a specific quantity, and it is unique. The words – numbers are connected by a new grammar which is mathematics and which – at least at the time of Galileo – provides connections without ambiguity. Thus science is built by univocal terms connected by necessary rules. Once a sufficient number of initial observations establishes a set of terms and of their connections (the natural "laws") one can extract all consequences by deduction, thus anticipating events before they occur. This is the predictability of science, a virtue absent in the ordinary language.

In the science of Galileo and Newton there is a precise correspondence between our mental procedures and the world events, since M extracts the relevant things neglecting the "secondary qualities", that is, those nuances which are useful for poetry but not scientific predictions. Within this framework, certitude (i.e. syntactical correctness) and truth (i.e. adequacy to reality) seem to coincide.

The complexity of the dynamical model of a many particle system can be seen as the ambiguity in predicting the state reached at a given time starting from a definite initial condition. Let us introduce the notion of "stability of a trajectory". Suppose we go by bicycle on a road laying in the bottom of a valley. Let such a road be unique. However a change of landscape may transform the valley into a ridge with two lateral valleys; if the rule is that the road has to be in the valley, then we have two roads. This duplication is called "bifurcation". The bicycle on the road is a metaphor of the system dynamics. The system is mathematically represented by a point in an n-dimensional space, where n is the number of different measurements by which we characterize the system. In the case of a single point-like particle, we need three coordinates for the position and three for the velocity, hence $n=6$; for a system of N particles, $n=6N$.

The time evolution of the system is the collection of successive state points, that is, a trajectory in the n dimensional space. The bifurcation is the transition from a trajectory with a single branch to a trajectory with two possible different branches.

The topography of the valley roads looks like a fork. In the "qualitative dynamics" of Poincaré, we plot the position of the stable dynamical states as a function of a control parameter. For all the control parameters which admit a single valley we have a continuous line; as the control parameter implies two valleys, that line bifurcates into two separate lines. This topography is called the bifurcation diagram.

The only knowledge of the topography does not allow to establish whether the system is taking one branch or the other. If each one of the separate branches bifurcates on its turn, and thus on, we have a tree whose branch number grows exponentially, that is, two after the first bifurcation, four after the second, eight after the third and so on. If we call "syntax" the assignment of the topography, we see that to resolve the ambiguity and decide on the precise branch, we must add some extra information at each bifurcation. This means that the "semantics" enters not only in the preparation of the model, as we choose the degrees of freedom, but also in the course of the evolution, since we must also decide how the environment breaks the symmetry of each bifurcation imposing a specific choice.

This is the main message of nonlinear dynamics. Before people realized this bifurcation explosion, it was considered safe to limit the investigation to a range of control parameters allowing for a single branch. However only in laboratory demonstration it is up to us to fix the control parameters; in real life, the piece of world that we aim to model is embedded in an environment which provides parameters not controllable by us. We should then be ready to face plenty of possible bifurcations.

Thus, complexity in science denotes two different things.

If we refer to a closed piece of world, removed from external influences, once the essential connotations have been captured into a model, then the deductive machine provides a tree of possible solutions, with many branches all equally likely. In such a case the complexity is syntactical, intrinsic to the formal language, in so far as it is due to in the presence of alternative paths. We can take as indicator of complexity the amount of computational resources necessary to solve the problem. This complexity, considered in computer science, will be rather called by us as complication.

More realistically, we must realize that a model of closed world is not very convenient. It is instead more useful to build the model upon some salient features on which we have detailed information, and consider the system under investigation as "open" to the rest of the world. This openness manifests itself as suitable "boundary conditions", that we must apply at each bifurcation to decide which side to continue.

## 4. The adaptive strategy and ontological openness

In a standard formalism the bifurcations occur at specific values of the control parameter assigned by the axiom set. We should then have a comprehensive axiom set to cope with all possible space and time scales from elementary particles to many phenomena of condensed matter and then to living bodies and to societies of autonomous individuals.

Such a dream, which was the way Laplace tried to extend the Newtonian model to all realities, is nullified by the occurrence of bifurcations (Anderson). To avoid the exponential explosion of the number of bifurcations, we rather change model as we focus on different problems, re-adjusting the axiom set, that is, the scientific model, for each situation (see Arecchi and Arecchi, Arecchi 1996).

The adaptive strategy corresponds to re-describing the same event from different points of view; it is a progressive adaptation; it does not grasp the reality in a single snapshot but it focuses on different approximations, giving up with a global and unique point of view. This gives a stability to a scientific theory, which has a degree of truth from a certain "point of view" even though it may be inadequate at different resolutions. For example, Einstein's gravitational theory has not made false Newton's theory but has delimited its range of validity, showing that it is true only from a certain point of view.

Taking the adaptive method as the cognitive procedure means recovering the role of the natural language, which has adaptable rules, but it also means reconsidering truth not a self-consistency within a fixed set of rules (the Descartes' criterion of clear and distinct ideas) but as the acknowledgment of a hierarchy of different levels of description reality.

As a conclusion, modern science rediscovers truth as "adaequatio", that is, it is founded upon an ontology, whereas the Cartesian criterion was suggesting that mathematicizing a science was sufficient to attribute to it a certitude. Due to this adaptive character, the search for truth is always a "work in progress", which implies a risk. On the contrary the certitude, even though self reassuring, may be uncorrelated with the elements of reality.

## 5. A physiological correlate of the adaptive strategy: the visual perception

While building a scientific description seems a specific human endeavor, building global perceptions out of elementary sensorial stimuli is a task common to all animals, even though with different degrees of sophistication. We show the role of adaptivity in such a cognitive task, with particular reference to vision (Arecchi and Farini, 1998).

Up to the sixties a reductionistic trend attempted to explain the global behavior of a cognitive agent in terms of elementary phenomena. This trend was based upon many experimental achievements, such as the explanation of the photochemical sensitization processes on the retina, and of the successive transformations into electrical pulse trains travelling on the axons of neurons, in virtue of a modulation of the ionic channels. These elementary physical processes were combined in networks, with the hope of reconstructing global perceptions.

On the other hand, holistic approaches, as the Gestalt psychology, emphasized the intrinsic character of the global perception which can not emerge as the simple sum of the atomic components. However, Gestalt statements could not be logically correlated to the elementary processes.

If the reductionistic approach had a universal validity, then the vision process could be reconstructed from elementary perception acts. In such a case each neuron should code a specific information and only that one (the theory of the "grandmother neuron"); thus any increase in knowledge would imply a growth of the neuron numbers and this is against the factual evidence.

The winning conjecture – corroborated by laboratory evidence – is that neurons have a further degree of freedom consisting in the possibility of temporal coding. Precisely, they act as nonlinear devices which fire trains of electrical short pulses (spikes) whose frequency (number of pulses per unit time) is proportional to the amount of excitation above a given threshold. This suggests how to explain the unitary perception of a figure with different degrees of luminosity, color and shape within it. It is sufficient that neurons appointed to detect specific characteristics synchronize their spike frequencies, so that they collectively contribute to the same individual configuration, such as e.g. the cat in fig.2. This occurs for a short time (a fraction of a second); later on the neurons are available to reorganize themselves in different collective states. This behavior is called "feature binding" (Singer and Gray, 1995).

However a problem arises: what agent is responsible for setting the thresholds? Certainly not the stimuli arriving bottom-up from the retina, since they differ from each other depending on the amount of signal in their receptive fields. It is required a feedback top-down from the semantic memory where previous meaningful patterns have been recorded. Following this conjecture the categories already memorized act as interpretational hypotheses (expectations). If the two streams of signals top-down and bottom-up match with each other, then there is a resonance, confirming that the external stimuli correspond to a coherent perception. This is the essence of the "adaptive resonance theory" (ART) (Grossberg, 1995).

ART resolves the dilemma stability-plasticity explaining how we are able to learn new facts without being obliged to forget other ones. Its fundamental doctrine consists in assuming that new perceptions are always compared with memories of past perceptions.

Let us consider the Eherenstein figure consisting in black radial lines symmetrically placed around a center (fig.3). Our mind builds an imaginary circle internal to the radial lines which makes the figure similar to a childish drawing of the sun. Indeed, the imaginary inner disk looks brighter than the background. Such a perception is an emergent collective property of all the lines which arises only when they are placed in a suitable way; it disappears in the drawing on the right. Why do we see a bright disk which does not exist?

A higher level of visual elaboration stays in the recognition categories, which control the expectation of what we might see, as a face or a letter.

The top down process (see fig. 4) amplifies selectivity some aspects of a stimulus and suppresses some others, helping to focus the attention on information corresponding to our expectations. This focusing process helps filtering some parts of the sensory signal, which would be otherwise incomprehensible, thus avoiding to destabilize previous categories already memorized: this is the solution of the dilemma stability – plasticity.

Combining ART with feature binding we can state that resonant brain states associated with a good matching between stimuli and expectations represent a conscious perception.

There is neurophysiological evidence that the feedback from the cortex to the lateral geniculate bodies works like an ART network (Munk et al., Grossberg).

How does the network react when the expectation top-down does not coincide with the configuration bottom-up? In such a case the cycle is repeated until one finds in the memory the correct category or one realizes to be in the presence of a novel feature which requires a new category.

In conclusion,

i) it is not true that sensations are recorded passively by an automatism stimulus-response, but any perception is the result of a dialogue between the cognitive agent, with its storage of past memories, and the outside world;

ii) solipsism and relativism are excluded by the inspecting mechanism (called focal attention in fig. 4) which assures that the top-down conjectures are confirmed by the bottom-up signals; otherwise, a novel experience must be classified;

iii) anyway, one can deceive him/herself under pathological situations by anomalous amounts of neurotransmitters which distort the synchronization process leading to non-realistic perceptions, that is hallucinations; such is the case of an individual under the effect of narcotics.

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## 6. Open science and the recovery of corporeity

We have seen that an open science is not based on deductions from a fixed axiom set, but it accepts new hypotheses (model changes) when focusing on novel aspects. This means (Anderson) that "more is different", it can not be described as a shear sum or mathematical combinations of concepts already tested to be valid for the "less", but it requires new concepts, or universals (Armstrong) which are peculiar of the complex natures, and therefore are not deducible from the component natures.

We thus consider the universals as real, and not just as linguistic tools. Let me make an example: a firm quoted in the stock market is real, since it gives rise to verifiable phenomena, but it emerges from a consensus among some partners. Neither the partners, nor the written text of the joint agreement, are sufficient to predict how the firm as a whole individual is going to compete on the market.

This holds especially for the human nature, and in this case there is in addition a well familiar dynamical aspect. Indeed, mental processes organize perceptions (individual and concrete) into concepts (univerals and abstract) by a confrontation of past memories and their reorganization into new categories. Associated with this mental capability of conceptualization, we witness a free will whereby our action may even be opposite to what suggested by the perception through the emotional channels.

Starting from the scientific acknowledgment of the human behavior as a complex system, we lay out the foundation of a phenomenology of the human nature, discovering those aspects of unity and freedom that philosophers attribute to a "person".

This shows the lack of depth of a socio-biological approach based on a dynamical model whose rules emerge from the animal behavior, thus overlooking the ethical responsibility.

The deterministic dynamics of socio-biology is incompatible with an open science. Even if the model captures the salient features of the piece of world under investigation, the corresponding bifurcation tree provides many possible solutions. Among all these "futures" which one will be ours? What agent decides at each bifurcation whether to go right or left ? It is the environment which imposes its "boundary conditions" even through we often replace a sensible accounting of the environmental influences by "chance" or "randomness".

It may be convenient, to summarize our ignorance of the environmental influences by a chance term, but without "ontologizing" it, as done in Democritus philosophy or more recently by Monod or Dawkins. In a similar way, AI people recur to a "oracle machine" which is the association of a universal Turing machine with a random number generator in order to overcome the two limitations of an algorithmic procedure, namely, intractability (as discussed above) and indecidability in the sense of Gödel theorem (Arecchi, 1996, 1999a). The oracle machine considers chance as a whimsical agent thus making it clear our impotence to introduce the environment into the formalism. On the contrary, the adaptation strategy re-adjusts the algorithm whenever an external element intervenes. This correction mechanism, which means giving up with the Cartesian cleanness of a deductive machine with fixed axioms, is a re-appraisal of "adaequatio"

What said thus far is clarified by the following example. In my research group, we investigate the chaotic behavior of a laser disturbed by the feedback of a small portion of its light output. This chaos can be described by n=3 degrees of freedom. If however the return of the feedback is delayed, the return signal affects the system when this has already lost memory of its past behavior, and therefore it is no longer correlated with the incoming disturbance.

It is like embedding the 3-dimensional systems in a space of higher dimension (e.g. 8). The extra 8-3=5 dimensions which were not included in the model represent the perturbation of the environment. If we stick to a fixed model, we predict plenty of alternative behavior and we do not know which one will in fact occur. If we exploit some extra information for an adaptive correction, then we can reliably predict a unique behavior (Arecchi, 1999b).

This is a laboratory example of the epistemic gap between a Cartesian model and an adaptive description. We have insisted on details, because the above example is a metaphor of our cognitive operations. Going back to fig. 1, the dashed line from S to M represents the resetting of our senses to adapt to the specific features of the reality R. The "self" is not S, but S+M, with the setting of M redone by pre-linguistic interventions which leave no record within the scientific description.

It is corporeity which puts us in tune with the world, saving us from abstractions. The pre-linguistic readjustment, which is the core of "adaequatio", has received several names, such as "abduction" by C.S. Peirce and "tacit dimensions" by M. Polanyi (for references, see Arecchi and Farini, 1996). It represents a harmonious dialogue with reality which guides the selection of hypotheses. Thus, the hypothesis is not an arbitrary invention to be falsified if it does not work, but it is the result of a patient inquiry.

Creativity means attentive openness toward the world, it implies a loving relation with the world. Whence an ethics of the relation man-world in science. This relation implies a respect for reality, without trying to force it into the Procustes bed of our mental schemes.

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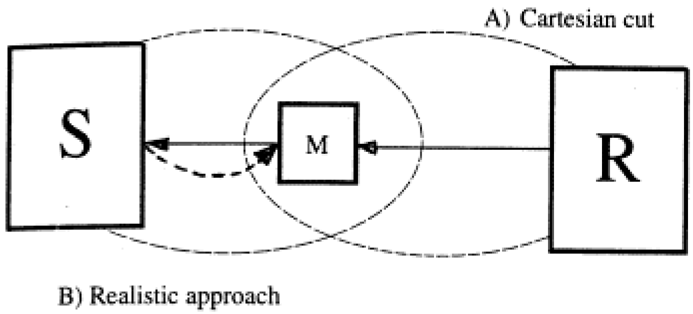


**Fig. 1.** Knowledge interpretation: R=reality, M=symbol generator (measuring apparatus), S=symbol interpreter (model builder).
Lline A (Cartesian cut) M+R provide representations as symbol sequences, which are processed by S. S can be replaced by a Turing machine.
Line B (Realistic approach): S+M globally face R. Before producing outputs, M is readjusted among a class of possible settings by a pre-linguistic procedure not expressible within the formal language which later M provides to S.
The thick dashed line from S to M represents the feedback which readjusts the setting of M.

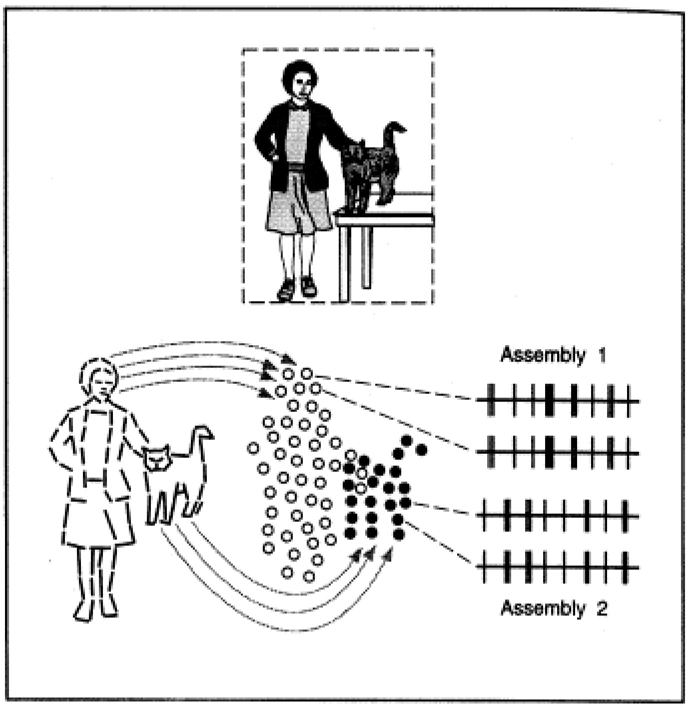


**Fig. 2.** Feature binding: the lady and the cat are respectively represented by the mosaic of empty and filled circles, each one representing the receptive field of a neuron group in the visual cortex. Within each circle the processing refers to a specific detail (e.g. contour orientation). The relations between details are coded by the temporal correlation among neurons, as shown by the same sequences of electrical pulses for two filled circles or two empty circles. Neurons referring to the same individual (e.g. the cat) have synchronous discharges, whereas their spikes are uncorrelated with those referring to another individual (the lady).

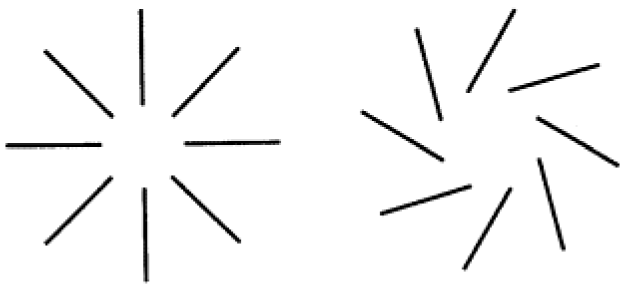

**Fig. 3.** On the left, Ehrenstein figure. We perceive an illusory circle, formed by the inner ends of the radial lines, which enclose an area which seems brighter. Such a perception disappears for a different organization of the lines (on the right).

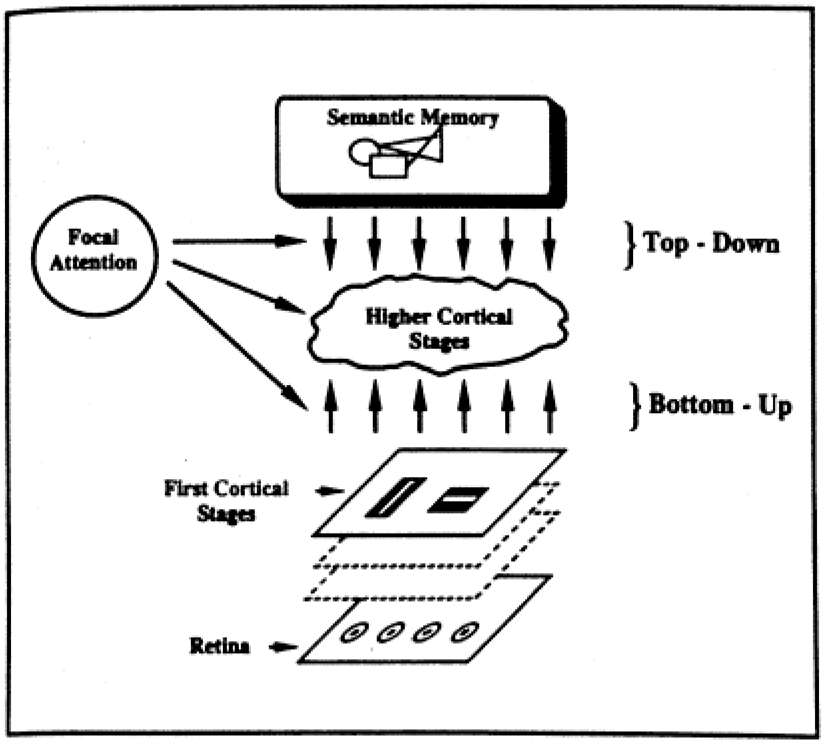


**Fig. 4.** ART = Adaptive Resonance Theory.
Role of bottom-up stimuli from the early visual stages an top-down signals due to expectations formulated by the semantic memory. The focal attention assures the matching (resonance) between the two streams.