Cognition and language: from apprehension to judgment – Quantum conjectures

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Abstract
We critically discuss the two moments of human cognition, namely, *apprehension* (A),whereby a coherent perception emerges from the recruitment of neuronal groups, and *judgment*(B),that entails the comparison of two apprehensions acquired at different times, coded in a suitable language and recalled by memory. (B) requires *self-consciousness,* in so far as the agent who expresses the judgment must be aware that the two apprehensions are submitted to his/her own scrutiny and that it is his/her duty to extract a mutual relation. Since (B) lasts around 3 seconds, the semantic value of the pieces under comparison must be decided within this time. This implies a fast search of the memory contents.
As a fact, exploring human subjects with sequences of simple words, we find evidence of a limited time window , corresponding to the memory retrieval of a linguistic item in order to match it with the next one in a text flow (be it literary, or musical,or figurative).
Classifying the information content of spike trains, an uncertainty relation emerges between the bit size of a word and its duration. This uncertainty is ruled by a quantum constant that can be given a numerical value and that has nothing to do with Planck's constant. A quantum conjecture might explain the onset and decay of the memory window connecting successive pieces of a linguistic text. The conjecture here formulated is applicable to other reported evidences of quantum effects in human cognitive processes, so far lacking a plausible framework since no efforts to assign a quantum constant have been associated.

Outline

This paper is a tribute to the late John S. Nicolis, a fine scientist who, already in the early 1980's, has pioneered the application of chaotic dynamics to brain processes . A review of his approach is reported in [Nicolis].

[Contribution to the volume in honour of John S. Nicolis :
***Chaos, Information Processing and Paradoxical Games*, G. Nicolis and V. Basios (eds), World Scientific, Singapore, 2013]**

1-Introduction on perception, judgment and self-consciousness

In [Arecchi2012a] I have developed the following approach. Following the hints on the philosophy of cognition provided by Bernard Lonergan [Lonergan], I have analyzed two distinct moments of human cognition, namely, *apprehension* (A) whereby a coherent perception emerges from the recruitment of neuronal groups, and *judgment* (B) whereby memory recalls previous (A) units coded in a suitable language, these units are compared and from comparison it follows the formulation of a judgment.

The first moment (A) has a duration around 1 sec; its associated neuronal correlate consists of the synchronization of the EEG (electro-encephalo-graphic) signals in the so-called gamma band (frequencies between 40 and 60 Hz) coming from distant cortical areas .It can be described as an interpretation of the sensorial stimuli on the basis of available algorithms, through a Bayes inference.

Precisely [Arecchi 2012a],calling ***h***(h= hypothesis) the interpretative hypotheses in presence of a sensorial stimulus ***d*** (d=datum), the Bayes inference selects the most plausible hypothesis ***h****,that determines the motor reaction, exploiting a memorized algorithm ***P(d|h),*** that represents the conditional probability that a datum ***d*** be the consequence of an hypothesis ***h.***

The ***P(d|h)*** have been learned during our past; they represent the equipment whereby a cognitive agent faces the world. By equipping a robot with a convenient set of ***P(d|h),*** we expect a sensible behavior.

The second moment (B) entails a comparison between two apprehensions (A) acquired at different times, coded in a given language and recalled by the memory. If, in analogy with (A), we call ***d*** the code of the second apprehension and ***h**** the code of the first one, now- at variance with (A)- ***h**** is already given; instead, the relation ***P(d|h)*** which connects them must be retrieved, it represents the ***conformity*** between ***d*** and ***h*,*** that is, the best interpretation of ***d*** in the light of ***h*.***

Thus, in linguistic operations, we compare two successive pieces of the text and extract the conformity of the second one on the basis of the first one. This is very different from (A), where there is no problem of conformity but of plausibility of ***h**** in view of a motor reaction.

Let us make two examples: a rabbit perceives a rustle behind a hedge and it runs away, without investigating whether it was a fox or just a blow of wind.

On the contrary, to catch the meaning of the 4-th verse of a poem, I must recover the 3-d verse of that same poem, since I do not have a-priori algorithms to provide a satisfactory answer.

Once the judgment, that is, the ***P(d|h)*** binding the codes of the two linguistic pieces in the best way, has been built, it becomes a memorized resource to which to recur whenever that text is presented again. It has acquired the status of the pre-learned algorithms that rule (A)

However-at variance with mechanized resources- whenever I re-read the same poem I can grasp new meanings that enrich the previous judgment ***P(d|h)***. As in any exposure to a text (literary, musical, figurative) a re-reading improves my understanding.

(B) requires about 3 seconds and entails *self-consciousness,* as the agent who expresses the judgment must be aware that the two successive apprehensions are both under his/her scrutiny and it is up to him/her to extract the mutual relation.

At variance with (A), (B) does not presuppose an algorithm, but rather it builds a new one through an ***inverse Bayes procedure*** [Arecchi2007 a,b,c]. This construction of a new algorithm is a sign of *creativity* and *decisional freedom*

Here the question emerges: can we provide a computing machine with the (B) capacity, so that it can emulate a human cognitive agent?[Turing].The answer is NOT, because (B) entails non-algorithmic jumps, insofar as the inverse Bayes procedure generates an *ad hoc* algorithm, by no means pre-existent.

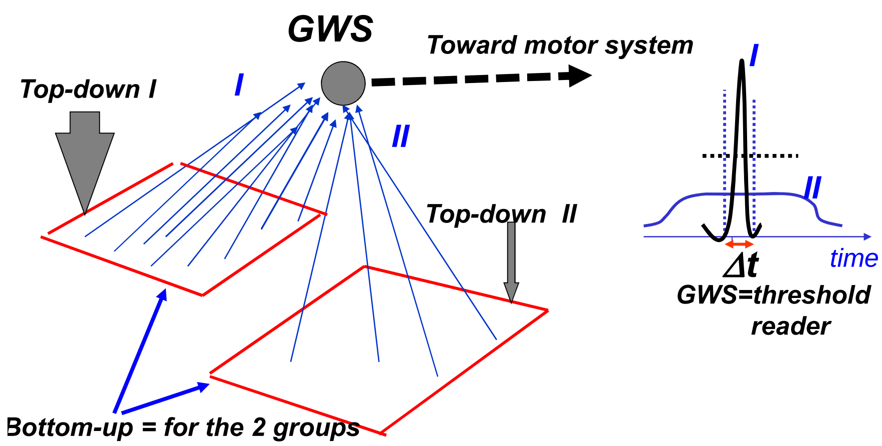
After having shown evidence of this short term memory window bridging successive pieces of a linguistic text, we formulate a quantum conjecture. This conjecture fulfills two needs, namely, i) explaining the fast search in a semantic space, whose sequential exploration by classical mechanisms would require extremely long times, incompatible with the cadence of a linguistic presentation; ii) introducing a fundamental uncertainty ruled by a quantum constant that yields a decoherence time fitting the short term memory window.
The memory enhancement associated with linguistic flows is an exclusively human operation, not applicable to a cognitive agent that operats ***recursively,*** exploiting algorithms already stored in the memory.
If the conjecture will be confirmed,the quantum mechanism would explain the a-posteriori construction of novel interpretational tools.
Elsewhere [Arecchi,2011,2012a)] I have shown that the creativity associated with (B) and absent in (A) is related to the incompleteness theorem by Kurt Goedel.

2- The transition from apprehension to judgment

We have stressed that one must distinguish two moments of human cognition, namely, ***apprehension (A),*** whereby a coherent perception emerges from the recruitment of neuronal groups, and manifests itself as a motor response, and ***judgment (B)*** whereby memory recalls previous (A) units coded in a convenient language and their comparison elicits the formulation of a judgment.

Without recurring to a naïve Cartesian dualism and based on phenomenology, by no means we should hold that (A) and (B) require different "instrumentation". As a fact, it is the same human brain that performs the operations leading (A) to a suitable motor response and (B) to the "best" reading of a text . In both cases, one must operate a choice among many possibilities. Over the recent years, neurosciences hypothesize a collective agreement of crowds of cortical neurons through the mutual synchronization of trains of electrical pulses (spikes) emitted individually by each neuron [Singer & Gray, Rieke et al., Victor&Purpura, Dehaene&Naccache] .The neuroscientific approach is summarized in Fig.1.
In my research group, rather than testing on living brains , we have simulated the dynamics of collective synchronization by building networks of chaotic physical components (lasers, LED= light emitting diodes, electronic circuits) each one displaying a dynamics similar to that of a single neuron and exploring the conditions of collective synchronization due to the combination of external signals and mutual couplings [Allaria et al., Al-Naimee et al., Ciszak et al., Marino et al.]

Dynamical implementation of Global Workspace (GWS)



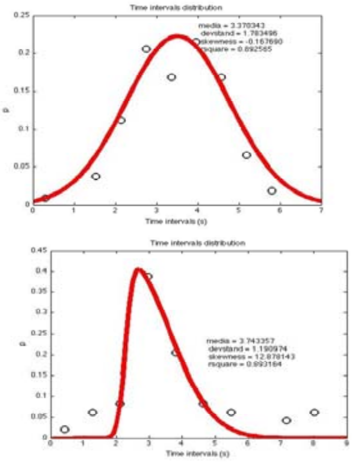
*2 neuron groups both excited by the same sensory stimulus **bottom-up**, but with different interpretations **top-down**, whence in **I,** neurons are syinchronized within time **Δt**, in **II they are not→ I prevails***

Fig.1- Competition between two cortical areas with different degrees of synchronization

Fig.1 visualizes the competition between two neuron groups ***I*** and ***II*** fed by the same sensorial (***bottom-up***) stimulus **d,** but perturbed ***(top-down***) by different interpretational stimuli ***P(d|h)*** provided by memory. ***I*** prevails , as the corresponding top-down algorithm ***P(d|h)*** succeeds in synchronizing the neuron pulses of this group better than what happens in group ***II.*** This means that during a time interval Δ***t,*** neurons of ***I*** sum up coherently their signals, whereas neurons of ***II*** are not co-ordinated. As a consequence a signal reader GWS(= global workspace, name given to the cortical area where signals from different areas converge) reads within Δ***t*** a sum signal overcoming a suitable threshold and hence eliciting a motor response [Dehaene].Thus ,using the jargon already introduced, the winning hypothesis ***h**** driving the motor system is that provided by ***I***.
What represented in Fig. 1 models the mechanism *(A)* common to any animal with a brain.

Altogether different is the situation for *(B),*that-implying the comparison between apprehensions coded in the same language (literary, musical, figurative, etc.) represents an activity exclusively human.
In fact, the second moment *(B)* entails the comparison of two apprehensions acquired at different times, coded in the same language and recalled by the memory.
(B) lasts around 3 sec; it requires ***self-consciousness,*** since the agent who performs the comparison must be aware that the two non simultaneous apprehensions are submitted to his/her scrutiny in order to extract a mutual relation.
At variance with*(A), (B)* does not presuppose an algorithm but it rather builds a new one through an ***inverse Bayes procedure*** introduced by [Arecchi,2008]. This construction of a new algorithm is the source of *creativity* and *decisional freedom.*
The first scientist who has explored the cognitive relevance of the 3sec interval has been Ernst Pöppel [Pöppel].
This new temporal segment has been little studied so far. All the so-called *"neural correlates of consciousness"(NCC)* are in fact electrical (EEG) or functional magnetic resonance *(fMRI)*tests of a neuronal recruitment stimulating a motor response through a GWS (see Fig.1); therefore they refer to (A). Rather than *consciousness* , one should say *awareness* that we have in common with animals.

The cognitive role of the 3 second interval has been explored by us on various subjects exposed to linguistic (literary and musical) texts. In Fig. 2 we report the statistical distribution of pauses in reading Canto XXXIII of Dante's Inferno by the speaker Roberto Benigni and in performing the First movement of Beethoven V Symphony (Director H.von Karajan).



Benigni XXXIII Inferno

Ascolto V Beethoven

Fig.2-Statistical distribution of pauses in the presentation of a literary or musical text. As one can see , the interval that has the highest probability is around 3 seconds.

We plan to explore the sequence of ocular fixations in looking at a figurative masterpiece. About this, preliminary reported tests [Noton & Stark] (see Fig.3 registration of ocular motions(saccades) as line segments and ocular fixations as thick points in exploring the head of Queen Nephertiti; the associated times were not measured).
We are implementing an eye-tracker device in order to track also the associated times.
This investigation has multiple applications. We list someones .

i) Also for figurative texts we expect a preminent role of the 3 sec interval;
ii) The sequence and duration of eye fixations would denote the most appropriate way of reading a figurative text. As in poetry and music we exploit interpreters (see Fig.2),similarly the sequence of ocular motions of an expertcould act as a guide for a beginner, opening a new way of enjoyment of figurative works;
iii) The sequence and duration of the eye fixations could provide useful hints to a market expert for the optimal presentation of a product.

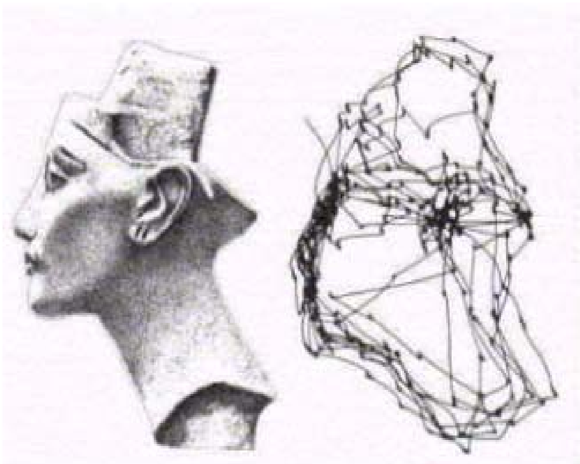


Fig.3-Sequence of ocular fixations in "reading" a figurative text[Noton&Stark]

Thus, while the perception of a sensory stimulus is interpreted via an algorithm retrieved by the "long term memory", in linguistic endeavours successive pieces of a text are related by the "short term memory".
Based on these considerations we have selected the most elementary lexicon (a sequence of figures with bistable interpretation) and collected quantitative data on the role of short term memory in visual tasks, observing maximal effects withina temporal window close to 3 sec, but variable from an individual to another.

3-Role of the short term memory in linguistic elaboration

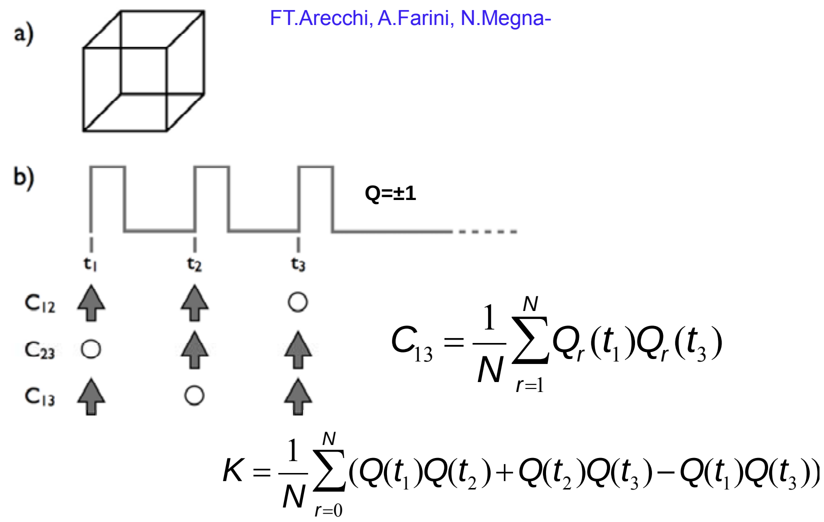
As stressed above, while in perception we compare sensorial stimuli with memories of past experiences, in judgment we compare a piece of a text coded in a specific language (literary, musical, figurative) with the preceding piece, recalled via the short term memory. Thus we do not refer to an event of our past life, but we compare two successive pieces of the same text. Such an operation requires that:

i) The cognitive agent be aware that he/she is the same examiner of the two pieces under scrutiny;
ii) The interpretation of the second piece based upon the previous one implies to have selected the most appropriate meanings of the previous piece in order to grant the best conformity (from a technical point of view, this conformity is what in the philosophy of cognition of Thomas Aquinas was defined as truth= ***adaequatio intellectus et rei*** *(loosely translated as* **:** *conformity between the intellectual expectation and the object under scrutiny)*

Operation ii) could require an excessively long time. For instance if the first piece is made of 10 words and each one has acquired – in the course of our life- 100 different meanings we should examine a table of 10x100=1000 different elements and all their possible combinations.
Nevertheless, the available time is only 3 sec, that is, the average interval between two successive verses of a poem, or two successive measures of a musical text, or two separate eye fixations on a painting. These 3 sec seem to be a common distinctive feature of all human languges. Presumably, it is the basis of the "universal grammar"[Chomsky].
After 3 sec, a new piece comes about before we have completed the connection between the two pieces under examination .To avoid the overlap of different pieces, we must repeat the sequence, as we usually do when we face a text for the first time and hence we do not succeed to build the appropriate ***P(d|h)*** at first shot.
On the other hand, we know that a quantum formalism can operate much faster by entangling the different meanings rather than presenting them sequentially.
Referring to the jargon already introduced for perceptions, we consider the end point of any brain operation as a successful synchronization between two spike sequences coding the items under comparison. The spike train that codes the second piece finds quickly the most similar train coding the meaning of the previous piece, without having to perform 1000 different trials in sequence.

Fig,.4 (upper part) shows how to build the three time correlations whose sum combines into the K function reported in the figure.
We expose the human subject under inquiry to a sequence of binary words. Such is the Necker cube, made only of contour lines, and displaying an ambiguity in the assignment of the anterior face. In correspondence to an acoustic signal (the arrow in the figure) the observer reports which anterior face he/ she has seen, by pressing one of two keys as +/-1. We correlate the +/-1 sequences,

building the sums over N observations. We repeat the operation for three pairs of times (1-2; 2-3; 1-3). The lower part of Fig. 4 reports an experimental test done over several human subjects. Testing different subjects and plotting the K values for different ISI (time intervals between stimuli), we see that all subjects display K>1 within a window of ISIs between 1 and 3 sec, as shown in the lower part of fig. 4 for a particular subject.



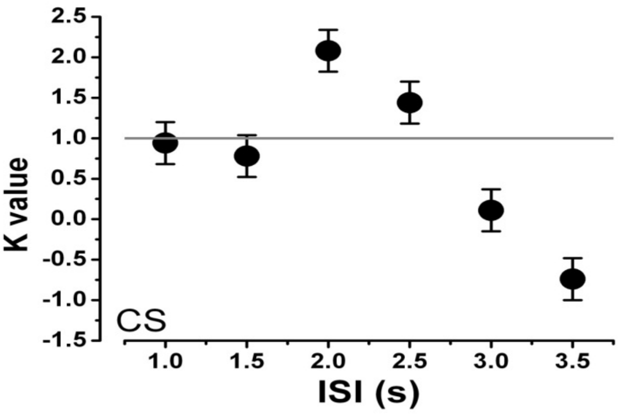


Fig.4- Evidence of a short term memory window in human cognition.[Arecchi,2013]. A) the Necker cube. b)experimental procedure: sequence of three successive presentations of the Necker cube (denoted by pulses, each of 0.25 sec duration) separated by ISI (interstimulus intervals); ISI= t_2*-*t_1 *=* t_3*-*t_2 *is adjustable from 1 sec on. The vertical arrows denote a sharp acoustic signal acting as a stimulus that demands the subject to press either button corresponding to the perceived front face of the cube.The circles denote the presentation of the cube in the absence of the acoustic signal. The three sequences correspond to* C_{12}*,* C_{23} *and* C_{13} *respectively.The sequences are repeated after a time >>* t_2*-*t_1*. The lowest figure shos that ageneric subject yields K>1 around 2 sec.*

We put forward the following interpretation.

Given a sequence of binary signals(+1,-1)we look for a sensitive test of the correlations among successive presentations.If the jump from +1 to -1 is random with a uniform distribution in time, the probability that the first inversion occurs at time t decays as exp(-t/ τ), where τ is the average separation between inversions (fig.5a). The probability that at least an inversion has occurred within ttime t is given by the integral approching 1 (certainty) for long times (fig. 5b). In the case of the Necker cube, the ptrobability of the first inversionin human subjects has been approximated by the gamma function [Borsellino et al.] (fig. 5c) e the integrated probability is given in fig 5d. At variance withfig5b, fig.5d displays aninitial correlation with the t=0 event, followed by a sharp rise .While fig.5b is uniformly convex,the short term memory changes the curvatureof fig. 5d from concave to convex.In collecting data on real subjects, the accuracy could mask such a difference. Furthermore, the gamma function of [Borsellino et al] corresponds to a continuous presentation of the Necker cube. Instead , as shown in fig.4, we look at a pulsed presentation, for a better simulation of the word variation in a linguistic flow.Therefore,we must find a combination of the correlation functions that not only discriminates beteween high andlowpart of fig.5, but also between continuous and pulsed presentation. Precisely, as shown in the expression of K reported in fig.4,we correlate the data at threetimes equally spaced. Since $t_2-t_1=t_3-t_2$, acontinuous presentation of the Necker cube yields $C_{12}=1-p_2$ (where p_2 is the value of the integrated probability at time t_2), whereas a pulsed presentation yield $C_{12}=C_{13}$.

It follows that in the absence of memory,K<1 always (fig.6,dotted),for a continuous presenattion of the Necker cube,K<1 again (fig.6, dashed),eventually in the pulsed presentation K>1 within a temporal window (fig. 6, solid).

Thus the K-test shows the role of the short term memory in a linguistic fllow.

To compare with a quantum research line, the K-test had also been considered [Leggett&Garg] as the time equivalent of Bell inequality [Bell]. However, in the Leggett-Garg case, each term of the three sums that yield C_{12}, C_{23} and C_{13} must be measured sequentially on the same system after a single preparation. On the contrary,we take separate averages for each of the Cij.Indeed,the same subject provides measurements of C_{12}, C_{23} and C_{13} ,but in three separate runs. For sake of brevity, in the following we call our K>1 evidence (figg.4 to 6) as p-LGI (pseudo-violation of the Leggett-Garg inequality).

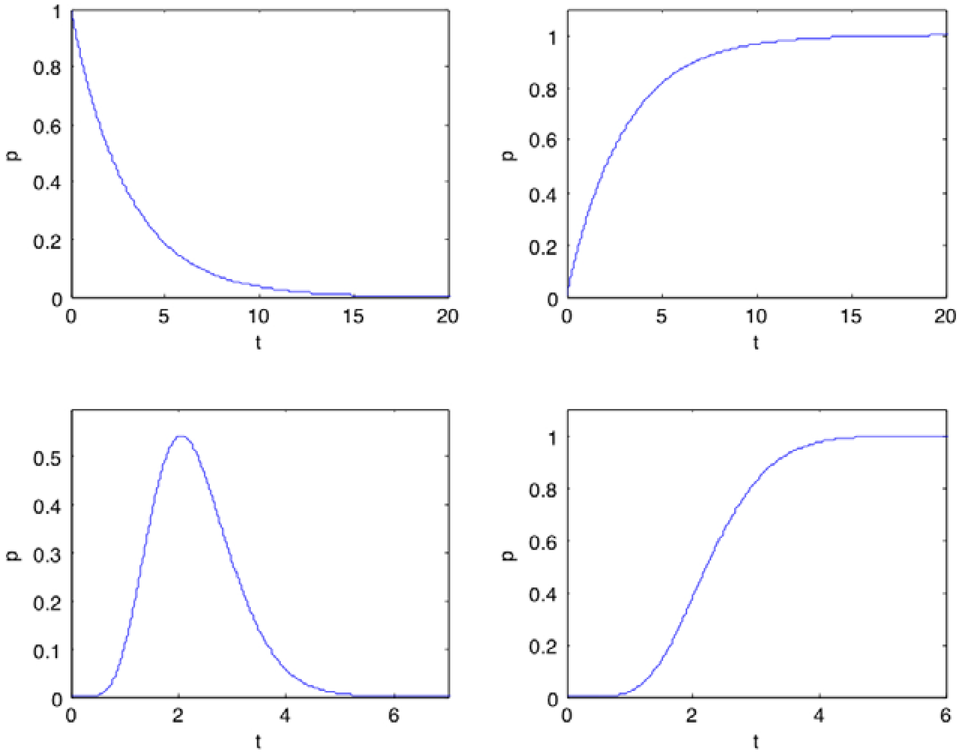


Fig. 5. a) (up-left) Probability to have a single switch at a time t for a sequence of random switches (uniform probability per unit time). b) (up-right) Probability that at least a switch is occurred at a time t for a sequence of random switches (uniform probability per unit time). The function corresponds to the integral of function in a). c)(down-left) Probability to have a single switch at a time t for the gamma distribution. d) (down-right) Probability that at least a switch is occurred at a time t for the gamma distribution;the function is the integral of the function in c)

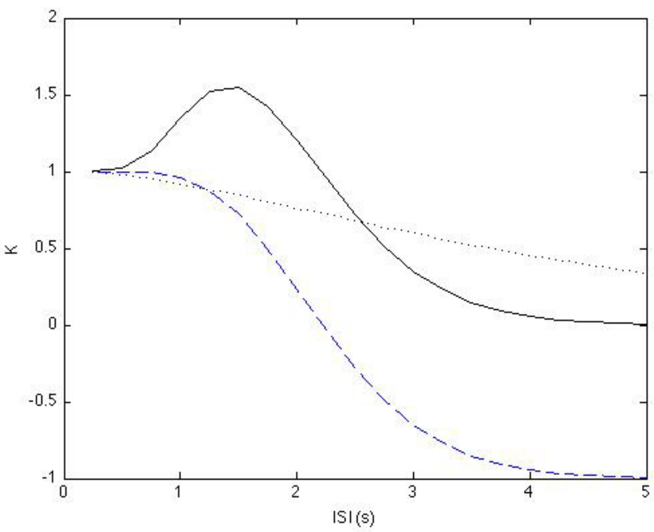


Fig.6. a) Computational K for random switches (dotted line), b) for gamma distribution in a continuous presentation (dashed line) and c) for a gamma distribution in a flashing presentation (continuous line) .It results that K>1 is the index of a short memorydeployment.

4-Quantum conjecture

In the previous section we have seen how a window around 3 sec connects two successive pieces of a text.This time seems too short to explore all possible meanings of the linguistic vectors (be they words, or musical notes, or small areas of a painting).

On the other hand,it is well known that a **quantum** comparison is much faster, since the different meanings aresimultaneously presentrather than sequentially.To adopt the neuroscientific jargon introduced for perceptions,the spike sequence coding the second piece finds rapidly the spike sequence coding the previous piece ,thus it cansynchronize to it without having to deal with 1000 successive trials.

If we search for a suitable quantum conjecture, we should explain the birth and death of correlations between successive words,which provide the temporal window K>1.

Taking inspiration from present quantum knowledge, we formulate some qualitative guesses

i) (rise time around 1 sec):the presentation of the second piece “forces” the network of memory to “condense” the famous 1000 meanings of the previous piece upon which the search has to be performed into a single presentation. The effect is reminiscent of a quantum effect called “Bose-Einstein condensation” in a network. This condensation starting from nodes governed by a “*fitness*” law has been studied theoretically [Bianconi-Barabasi]. In the case of a judgment , the *fitness* to be assigned to each of the1000 different items implies a subjective choice. Here the self-consciousness of the judging agent plays its own role. This interpretation is rather qualitative. Presumably what in the network language is *fitness* is equivalent to what in Damasio’s parlance is “*emotion*” even though in Damasio there is no attempt to insert it into a network dynamics [Damasio].

ii) (decay time around 3 sec): a quantum effect called “*coherence*” consists of a “phase” agreement of the complex numbers representative of the physical state; when the phase information is lost the corresponding real numbers implement a classical formalism. The phase loss, called “*decoherence*” , is due to the interaction of the system under investigation with the rest of the world (so-called “environment”). We expect a similar loss of the correlations introduced in i).

In the case of the brain, trying to understand it in terms of its constituent molecules would be a “*mereological fallacy*”. This term denotes the error of believing that a structured object is completely described by the properties of its constituent parts, as tested in the laboratory for homogeneous systems of variable volume but consisting of the same microscopic components (atoms, molecules, photons). Extrapolating this feature to non-homogeneous entities would correspond to believing that if a madman destroys by a hammer Michelangelo’s David, the heap of fragments keeps the information and allows the reconstruction .

A mereological fallacy for the brain would be to attribute to its operations a decoherence time based on its individual molecules. The decoherence time at room temperature of a brain molecule is 10^{-14} sec, thus for all cognitive purposes a quantum behavior is irrelevant. The calculation [Tegmark] is based on the following considerations.

The room temperature disturbance has an energy (k_B being the Boltzmann constant)

$$k_B T = 0.025\ eV \approx 4 \cdot 10^{-21}\ joules$$

The time necessary for this energy to overcome the quantum constrain (represented by Planck’s constant h), that is,

$$Energy \cdot time > h/(2\pi) = 10^{-34}\ joules \cdot sec$$

is just 10^{-14} sec. This reasoning is widespread in the scientific community [Koch&Hepp].
Let us explore how *quantumness* properties can be extrapolated from single microscopic objects to the mental operations of a cognitive agent . We introduce the notion of *quantum-like* rather than *quantum* behaviour [Khrennikov, Busemeyer&Bruza]. I have shown [Arecchi, several papers between 2003 and 2012b,in particular Ch.9 of the book Arecchi,2004a)] that a network of distinct individuals exchanging sequences of spikes and that misses synchronization because of plus or minus a single spike, has a decoherence time which is just 3 sec!
Indeed, in quantizing the synchronization dynamics of neural spikes, Planck's constant must be replaced by the new constant C such that

$$C \cong 10^{22}\hbar \ .$$

Furthermore, the elementary disturbance due to one more or to one less spike requires the opening of 10^7 ion channels in the axon of a neuron. Each channel requires the conversion energy of ATP□ADP+P corresponding to $0.3\ eV$, thus the energy of the elementary disturbance is 10 million times higher than the molecular room temperature disturbance $k_BT=0.025\ eV$!
The time necessary to the elementary disturbance to overtake C is precisely 3 sec. This is thus the decoherence time for the loss of quantum aspects in neural synchronization.
Discussing this robustness to environmental noise of a brain made of neurons (even most elementary brains as worms') , my friend Federico Faggin noticed that even unicellular beings, even though living comfortably at T=300K, have a higher threshold of disturbance in their information exchange. Indeed a paramecium, to activate its ciliar motion, needs at least one conversion ATP->ADP+P, that entails an energy above 10 times the room temperature k_BT .
Consequences
i) The formulation of judgments (upon which free decisions are based) is exclusively human; it requires self-consciousness.
i) In autistic subjects, the decoupling form environmental disturbances might last well beyond 3 sec. It would be worth to investigate if a time extended quantum behavior is responsible for those outstanding calculation capabilities called "*Hypercalculia*"
In manipulating spike trains, in order to evaluate the time correlations one has to make use of the Wigner function W[Wigner] as discussed in [Arecchi,2003,2004,2005] .

While a "local" measuring device reads the value of an observable at a point (r,t) of space-time, the Wigner device is "non-local" as it correlates readings belonging to separate space-time points, yielding also negative values as it occurs in an interference experiment.
My criticism to some microscopic physics interpretations is that the quantum formalism does not reveal the "ontological" mechanisms of the micro-world but it just relates to what is accessible to our measurements.
If we consider the measuring apparatus as "local", then we get the value of an observable at a given point (r, t) of space-time. On the contrary, a time code implies a Wigner non-local measurement that stores data , ordered by a phase factor, and reads them globally.
This statement is better explained by reference to a Young interference experiment (Fig.7).
If non-locality means dealing with a quantum procedure , then two questions must be answered, namely,
i) what is the constant C that replaces Planck's constant in the formalism of the brain code?
ii) can we foresee a quantum computation based on the time code, in a network of spike sequence, and what are the decoherence processes that limit such a behavior?

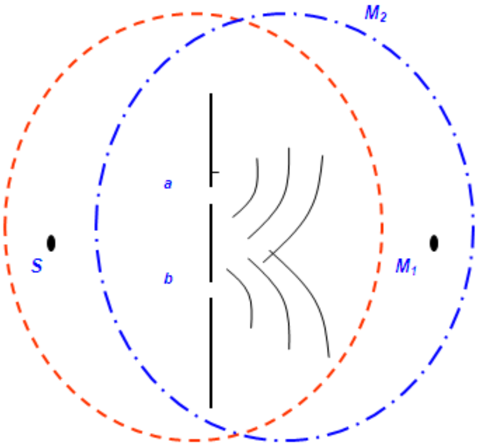


Fig.7 Young experiment: between a light source S and a local meter M_1 ,one inserts a screen with two slits a and b at variable separation; by changing the separation a- b , M_1 records peaks and valleys of an interference signal.. ***Current interpretation****: the object being investigated is a complex source made by S and the screen (confined within the dashed oval) ; the two slits are sources of spherical waves that meet on M_1 with mutual phase depending on the position of a and b. Equivalent* ***non-local*** *interpretation: the source S gives no interference "per se". The nonlocal measuring apparatus M_2=M_1+a+b (confined within the dash-dot oval) generates fringes of height variable with the separation a-b. This is equivalent to monitoring a Wigner distribution.*

5-Entropy of perceptions and quantum of action

Let us summarize the neurophysiological data. Today we have acquired sufficient evidence that the information elaboration in the brain cortex is based on the synchronization of spike trains associated with distinct cortical areas. For each neuron,the relevant information is contained in a spike train of duration around 200 ms, made of spikes each lasting 1ms, with minimal separation of 3 ms and average separation (in the so called EEG gamma band) of 25 ms. From now on,we call ISI (inter-spike interval) the time separation of two successive spikes. Calling bin a time box of 3 ms duration, each bin has a pulse or is empty, along a binary code(0/1 bits). Therefore we have a maximum number P_M of bits given by [Victor&Purpura]

$$P_M = 2^{200/3} \cong 2^{66} \cong 10^{22}.$$

But not all sequences have equal probability; for instance, 0000000…. or 11111111…. Are very unlikely. Weighting with the above mentioned average separation of 25 ms, we find an entropy per unit time that amounts to a reduction coefficient $\alpha = 0{,}54$.[Strong et al.] of the exponent 66. Thus the number of bits over 200 ms is

$$\boxed{P_M = 2^{0{,}54\cdot 66} \cong 10^{11}}$$

Taking into account that we have, at most 5 distinct perceptions per second,and the human life span is about $3 \cdot 10^9$ sec , then the maximum number of perceptions to be stored is $1{,}5 \cdot 10^{10}$,that is,15% of the calculated capacity.Even within such a gross calculation,it results that the evolution has equipped humans with a brain adequate to the life span.

Let us now truncate a perception at a time $\Delta T < \overline{T}$. We call ΔP an indetermination in the number of perceptions, given by the number of all perceptions whose ISI are identical up to ΔT and that differ at least by one bit in the interval $\overline{T} - \Delta T$.

We have

$$\Delta P = 2^{\alpha(T - \Delta T)} = P_M \cdot 2^{-\alpha \Delta T}$$

We approximate this uncertainty relation with an hyperbola tangent at a given point. Due to the large difference between exponential and hyperbola,the value we calculate is sensitive to ΔT .

A suitable approximation in the ΔT range peculiar of perceptual processes provides

$$\Delta P \Delta T \equiv C = \textbf{620 words x bins}$$

If one selects a different ΔT, then a different C is obtained; thus the value here reported is just preliminary and it must be refined.

We convert to physical units of (energy)x(time) =(joules)x(seconds) (*Js)* in order to compare C with Planck's constant $\hbar$ of standard quantum mechanics.

One bin corresponds to 3 ms. A jump of word corresponds to a spike jump (one less or one more). To activate a spike ,the axon must open 10^7 ion channels, each one requiring a conversion energy ATP/ADP corresponding to 0.3 eV. I recall the conversion factor ***1 eV ≈ 10^{-19} J.***

Thus a spike/word requires

$$0.3 \cdot 10^7 eV \cong 10^{-12} J$$

Multiplying by 620 and converting *1bin=3 ms,*we obtain the conversion factor

$$\Delta P \Delta T \equiv C = 10^{-12} Js \cong 10^{22} h$$

C is the quantum of the perceptual code. We have carefully avoided a microphysical approach in terms of Planck's constant.

We have already called ***"mereological fallacy"*** the logical transition from a ***part***≡ *microtubule* [Penrose] or ≡*coherence domain of H_2O dipoles* [Vitiello] to the ***whole*** ≡ *brain*.

The transition works for homogeneous laboratory objects as one goes from 1 to N>>1 atoms or photons keeping the same behavior besides a scale factor, but it has no sense when we base the measurement act upon structured objects as the spikes for which there is no elementary equivalent, as we can not scale from spike trains to spike micro-trains.

In fact,the spike synchronization refers to networks of neurons already mutually connected,whereas the passage from one micro-tubule (size a few nanometers) or a coherence domain of H_2O dipoles (size below the millimeter) to extended regions of the brain cortex entails the passage through frontiers between heterogeneous structures (membranes) so hat any quantum coherence gets lost.

In conclusion, the synchronization dynamics of a network with fixed connections has nothing to share with the free particle dynamics upon which classical dynamics (Galileo, Newton, Hamilton) and Planck's quantization have been built.

In conclusion, we are introducing uncertainty requirements specific of brain spike synchronization.

The associated quantum constant *C* is the basis to establish a quantum computation and evaluate the corresponding decoherence processes.

Note. This approach,based on the uncertainty

" bit number-duration of spike train"

has provided a novel quantum formalism peculiar of the spike synchronization dynamics that rules cortical computations. Since it does not rely on Newtonian particle dynamics, it does not have to recur to Planck's constant, as instead done in early quantum hypotheses on neurotransmitters [Katz], later expanded by Penrose and Hameroff with reference to microtubules in the neuron cytoskeleton [Penrose1994, Hagan etal 2002].

6-Onset of the quantum behavior

We have already explained the end of the p-LGI violation in terms of decoherence. On the other side of the time window within which p-LGI is violated, why a linguistic elaboration has to consider the uprising of a quantum-like behavior?
This is the least settled part of the problem. Let us go back to the search of the most appropriate meanings of piece #1, in order to interpret piece #2. (Here, the sign # numbers the pieces of a linguistic text separated by about 3 sec).
We must build the conditional probability $P(2|1)$ that #2follows as a consequence of #1.
At the perceptual level, these conditional probabilities are memorized algorithms that extract the most plausible hypothesis by Bayes inference.
In perception, #1 and #2 are neither separated by 3 sec nor coded in the same code. It happens that upon the arrival of any stimulus *(#2=d=datum)*, the agent responds within less than 0.5 sec with an hypothesis *#1=h* and immediately the memory stirs up the most plausible consequence of *h* , that is, $P(d|h)$; however if *d* does not correspond to #2, then *h* was wrong and must be replaced until one arrives to h^* such that $P(d|h^*)$ be maximized. This is Bayes inference.
Such a chain

[sensorial stimulus-> interpretation based on previous memories –>motor reaction]

holds for any brainy animal; in particular, mammals close to us have reaction modalities close to ours and are fit for laboratory investigation, replacing humans.
This replacement fails if we explore linguistic processes, where both the input stimulus and the associated reply are coded and the comparison must be performed within the same code.
In linguistic transactions, $P(2|1)$ does not pre-exist, but it must be built on the spot, since #1and #2 are experienced for the first time (think of a new music or poem).
It is reasonable to assume that 1 sec is necessary to recall from memory all the panoply of meanings that the words of piece #1 have acquired in our life. But to choose the most appropriate meanings we have only 3 sec.(as shown in Fig.2, 3 sec seems universal for all humans).
We have just the window between 1 and 3 sec to build $P(2|1)$, thus we must activate a quantum search to be effective. How does this occur?
In a brain network the connections are stabilized in the first years of our life.
On the contrary, in a volume confining free particles, the relevant problem is if/how the thermal DeBroglie length λ_{DB} (that allows quantum correlations) compares with the mutual particle distance. λ_{DB} includes the Planck constant , the particle mass and the temperature; it is larger the smaller are mass and temperature .This particle model is the basis of quantum approaches of

consciousness , starting from Frölich [Frölich] and Penrose-Hameroff [Penrose, Hagan etal.,Vitiello].
In a way completely different from free particles, the selection in a meaning space entails the exploration among objects already coded in the neural code as spike sequences. Thus, this exploration must be seen as a “random network” (network of nodes with apparently random links, since they are not bound to an ordered lattice). The propensity of two nodes to establish a mutual link depends on a mutual attraction called *“fitness”* [Bianconi-Barabasi].

We thus conjecture that a linguistic elaboration is the exploration of a semantic space that we model as a constellation of nodes. We attribute to each node a fitness corresponding to the “value” that the corresponding word (I say “word” in general, referring also to music [=sequence of tones] or painting [=group of lines and colors]) has acquired in our own cultural and emotional life.
A variable fitness can produce a Bose-Einstein condensation (BEC),where the particle number corresponds to the number of links that bind a node to the others [Bianconi-Barabasi].

Peculiarity of a BEC: a BEC behaves as a quantum computer, with the computation times reduced in the ratio $t \rightarrow t/N$, where N is the number of condensed particles [Byrnes et al.].

7-Comparison with other approaches to quantum cognition

We have already criticized the mereological fallacy.
Models of quantum behavior in language and decision taking have already been considered by several Authors but without a dynamical basis, starting 1995 [Aerts]; and over the past decade [Khrennikov]. Most references are collected in a recent book [Busemeyer&Bruza].

None of these Authors worries about the quantum constant that must replace Planck’s constant. However,a quantum behavior entails pairs of incompatible variables, whose measurement uncertainties are bound by a quantization constant, as Planck’s in the original formulation of Heisenberg. One can not apply a quantum formalism without having specified the quantum constant ruling the formalism. For this reason, all reported quantum tentatives must be considered flawed.

Furthermore, there are a few misunderstandings to clarify. We illustrate some.
1)-As one tries to explain Tverski and Kahneman paradox on Linda (Fig.8, [Busemeyer&Bruza], one applies sequentially two projections on a Hilbert space. The operation has no formal justification. One should rather build time correlations and check for a p-LGI violation, as we did.

2)-When one speaks of interference between bistable perceptions [Conte et al], one refers to a specific time separation, without exploring whether the interference disappears outside a time window corresponding to the timing of linguistic operations.

3)--Suppes and Acacio de Barros [Acacio de Barros & Suppes] speak of *quantum-like behaviour*,
that they attribute to classical oscillators without a quantum basis whereby they explain the interference reported at 2) . However they exclude the possibility of testing quantum behaviours as violation of Bell inequalities, since the simultaneous measurement (within a resolution better than fractions of microsecons) at two sites located *space-like* can not be done within the brain. This is a
conceptual error because they have in mind signals traveling at the light speed, whereas the neuron signals travel at about 1 m/s, so that a separation of 10 cm is *space-like* up to times of 100 ms (since
one can not transmit information over shorter times).

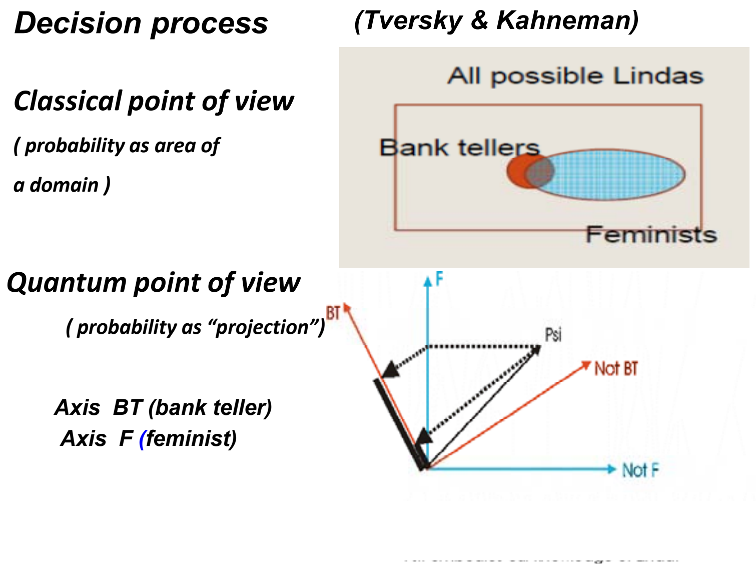


Fig.8-The Linda paradox: Linda is described as extrovert and feminist; two question are asked:
1)Is Linda a bank teller?
2)Is Linda a bank teller and a feminist?
The majority of participants discard 1) and accept 2).
This is against classical probability (upper part of the figure) according to which the probability of 1) is area of the circle "bank tellers", while the probability of 2) is the area of the intersection between the domain "bank tellers" and the domain "feminists", hence 2) can never overcome 1).

From a quantum point of view (lower figure) we are in a vector space (called Hilbert space) and states are represented by vectors. Our knowledge on Linda is represented by vector Psi. The probabilities are the lengths of the projections of Psi on the axes F or BT. The direct projection of Psi on BT is small. However if we first on F and then project this projection on BT, we obtain a larger probability.

<u>*8- Current misunderstandings between apprehensions and judgments*</u>

In Fig. 1 we have generically denoted as *top-down* the luggage of inner resources (emotions, attention) that, upon the arrival of a bottom-up stimulus, are responsible for selecting the model $P(d|h)$ that infers the most plausible interpretation h^* driving the motor response. The *focal attention* mechanisms can be explored through the so-called NCC (Neural Correlates of Consciousness) [Crick&Koch] related to EEG measurements that point the cortical areas where there is intense electrical activity producing spikes, or to f-MRI (functional magnetic resonance imaging) that shows the cortical areas with large activity which need the influx of oxygenated blood.

Here one should avoid a current confusion. The fact that a stimulus elicits some emotion has NOTHING to do with the judgment that settles a linguistic comparison. As a fact, NCC does not reveal self-consciousness, but just the awareness of an external stimulus to which one must react. Such awareness is common to animals, indeed many tests of NCC are done on laboratory animals.

It is then erroneous to state that a word isolated from its context has an aesthetical quality because of its musical or evocative power. In the same way, it is erroneous to attribute an autonomous value to a single spot of color in a painting independently from the comparison with the neighboring areas.
All those “excitations” observed by fMRI refer to emotions related to apprehension and are inadequate to shed light on the judgment process.
Let me formulate a conjecture based on what said in the previous Sections. The different semantic values that a word can take are associated with different emotions stored in the memory with different codes (that is, spike trains). Among all the different values, the cognitive operation “judgment” selects that one that provides the maximum synchronization with the successive piece (and here I have hypothesized a relation to the fitness of nodes in a network).
Thus emotions are necessary but not sufficient to establish a judgment. On the other hand, emotions are necessary and sufficient to establish the apprehension as they represent the algorithms of the direct Bayes inference. This entails a competition in GWS as indicated in Fig.1,where the winner is the most plausible one [Dehaene]; whereas in the judgment-once evoked the panoply of meanings to be attributed to the previous piece- these meanings do not compete in a threshold process (as in Fig.1), but they must be compared with the code of the next word in order to select the best interpretation, consisting in the most accurate synchronization.
Recent new terms starting with *neuro-* (as e.g. neuroethics, neuroaesthetics, neuroeconomy, neurotheology) smuggle as shear emotional reactions decisions that instead are based on judgments. The papers using those terms overlook the deep difference between apprehensions and judgments.
A very successful research line deals with *mirror neurons* ,that is, neurons that activate in subjects (humans or higher animals) observing another subject performing a specific action, and hence stimulate mimetic reactions [Rizzolatti]. Here too ,we are in presence of mechanisms (empathy)limited to the emotional sphere, that is, very useful for formulating an apprehension, not a judgment.

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