The Quantum Human Computer Hypothesis and Radical Minimalism:

A Brief Introduction to Quantum Linguistics

Diego Krivochen, UNLP. E-mail: diegokrivochen@hotmail.com

0. Introduction:

In this paper we will compare and contrast two models of computers: digital computers and quantum computers. We will follow Salmani-Nodoushan (2008) in his claim that the human mind works like a quantum computer, and will offer conceptual and empirical evidence that this approach leads to a minimalist model of mind. We will see that the *Quantum Human Computer Hypothesis* must nevertheless be completed with a more local theory of mental faculties, and that is where *Radical Minimalism* (Krivochen, 2011a et.seq.) comes into play. Our aim will be to build a stipulation-free theory of the quantum mind-brain under Radically Minimalist tenets.

Keywords: quantum linguistics, Radical Minimalism, Quantum Human Computer, digital computer

1. Salmani-Nodoushan's (2008) proposal:

1.1 The Digital Computer (DC):

The digital computer works by transforming an input in a series of 1 and 0 called a *bit*, regardless the input's nature or inner complexity. Once in its binary form, the information can be manipulated by the computer in a simpler way, since there is a unification of the format. The states 1 and 0 are, crucially, mutually exclusive. The formal expression of this operation is a rewriting rule of the form:

i) X ⟶ Y

Notice that this transduction (in Fodor's terms) is *crash-proof*, as was early Generative syntax (Standard Theory, Extended Standard Theory). There is a 1-to-1 correspondence between input and output, so that *no* "ill-formed sequences" can be generated:

ii) A ⟶ 1000001

iii) S ⟶ NP VP

The generative procedure is a fixed algorithm, one of whose forms is a sequence of divisions by 2 of any natural number, until the reminder in each division equals 0 or 1. The result is again divided by 2, as many times as needed, until it becomes zero. This is a simple *base component generative rule*, which operates with a reduced lexicon, namely, LEX = {1, 0}. Unlike EST, however, there is no *transformational component*, which makes this binary grammar very simple but descriptively and explanatorily inadequate for natural languages. The grammar is stipulatively *crash proof*, as the generation of ill-formed sequences is banned *by the very nature of the generative component*, not by the nature of any interface requirement[1]. We are in presence of a *context-free* generative algorithm.

After the *transduction*, the computer can process the information: electrical pulses are manipulated by electrical circuits to perform simple mathematical computations: 1 is *on* and 0 is *off*. It is known that rewriting rules are familiar to mathematics, and can generate interesting mathematical patterns. For example, let us take the following "grammar":

iv) 0 $\longrightarrow$ 1

v) 1 $\longrightarrow$ 0 1

If the reader develops the rules, s/he will see that the result is the Fibonacci sequence, adding the values of the nodes in the same level. However, there is a fundamental difference between DC rules and grammatical rules: the possibility of recursion. In this framework, we will say that a rule allows recursion if X is contained in some derivational point of the development of Y. For example:

vi) S $\longrightarrow$ NP VP

vii) VP $\longrightarrow$ V (+NP) (+PP) (+S)

The digital computer can be analyzed as a non-recursive manipulator of discrete units, consisting mainly of an algorithm for transduction, a working area for the performance of mathematical operations and an active operation that performs those computations. The operations are strictly linear and sequential, and all steps have to be fulfilled in order to have a successful derivation.

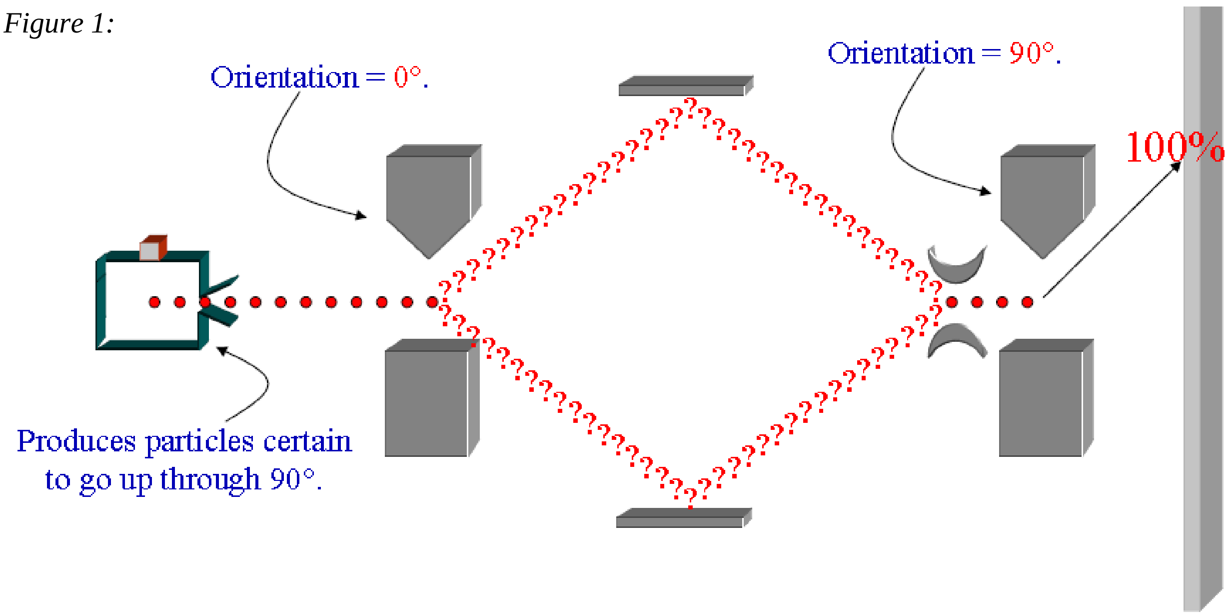
A more abstract sense in which we can think of a DC is a system that does not allow an object X to comprise several states at once. This can be seen as a simplification of the system, since it allows only 1-to-1 correlations between objects, but it also means that the characteristics of the relevant objects must be determined beforehand in a stipulative way. Besides, as we will see below, this system fails to capture many properties of natural languages. We will analyze this in depth when reviewing the features of Quantum Computers.

1.2 <u>The Quantum Computer (QC):</u>

[1] For a deep analysis of the possibility of crash-proof syntax, see Putnam (2010).

The main characteristic of QC is that they are not limited by the nature of binary *bits*, *either 1 or 0*, but they can work with 1 and 0 simultaneously. This means that there is no discretion in the definition of the units, which can be expressed as a "wave function" in isolation: prior to observation, the *quantum bit* or *qbit* is both 1 and 0, an undetermined state of a quantum field. Observation, according to Heisemberg (1999), collapses the state to one of the possible outcomes, in our particular case, 1 and 0. Of course, the possible outcomes of the quantum function can be more than 2, in which case the isolated element would comprise as many states as necessary. Theoretical experiments have been conceived, dealing with a photon's trajectory after several beam splitters (as shown in Salmani-Nodoushan, 2008) or an electron's spin after several deflectors, as in the example below (from *Philosophy of Quantum Mechanics* MIT course Spring 2005):

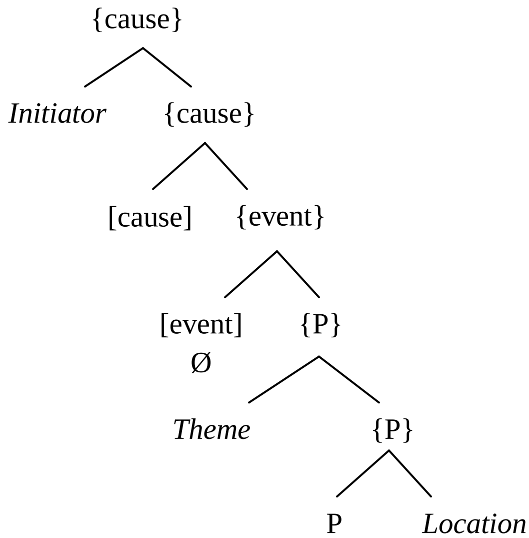
Figure 1:



Salmani-Nodoushan's hypothesis is that *the human mind could work like a Quantum Computer*, with its "fuzzy logic". This is called the ***Quantum Human Computer Hypothesis***.

The advantages of the QHC hypothesis are clear: it can perform many more operations in less time than DC. DC are constrained by what has been called "*the hundred step rule*" (see Carreiras, 1997), which establishes that, at most, a computer can perform a hundred sequential derivational steps per second, and many tasks require more than this. A QHC could perform "*billions of computations in no time*" (Salmani-Nodoushan, 2008: 30). QHC allows the mind to process information coming from faculties directly related with the phenomenological world (e.g., the visual faculty) and logic units (presumably *procedural*, taking into account that according to Leonetti & Escandell Vidal, 2000, procedural categories do not have an *encyclopedic* entry, but they do activate a *logical* entry that determines the relation that the procedural element will establish between an *n* number of conceptual elements) in a multidimensional space. Salmani-Nodoushan posits the existence of a *sense/logical distributor*, which we identify with the *conceptual locator* of Relevance Theory. This locator, as any other "abstract" entity is not for us "(…) *an ensemble of psyche, memory, mind, soul and spirit* (…)" (Salmani-Nodoushan, 2008: 30) but the result of the interaction of the prefrontal cortex and a certain specific area of the brain (following D'Espósito, 2007), with which the proposal gains biological plausibility and terminological rigour. Salmani-Nodoushan also proposes the existence of a second locator, in order to get to which information goes through several "filters", thus being enrichened with information coming from many different sources (cultural knowledge, pragmatics, semantics, etc.). A disadvantage we find in this point is that there is no principled way to determine the path information follows. This can easily lead to a chaotic space, rather than a quantum field, in the sense that everything is possible, and we will see that, if the mind is optimally designed, there must be some principled, third-factor constraints (in the sense of Chomsky, 2005: factors non specific to a mental faculty). We have built a case for Relevance Principles as third factor principles in our previous papers, and we maintain that position here. *Optimal Relevance*, understood as a biological adaptation (Manuel Leonetti, p.c.) seems to us to be a plausible universal rector of mental operations.

Information enters the mind chaotically, but it is organized in very much a Kantian way, into categories that exist as *a priori* forms: mainly, *space* (if we accept that *time* is conceptualized as a metaphor of space). However, the existence of more complex conceptual templates must be posited, as our awareness and understanding of the phenomenological world around us does not limit to *things* in a *location* (be it concrete or abstract). In previous works, we have depicted a theory of semantic primitives, which we will sum up here. Ontogenetically (and, perhaps, phylogenetically), the most primitive category is the *noun*, denoting *things*. Things, however, are not isolated, but related in various ways, the most basic of which is a purely *spatial* relation in terms of *central* or *terminal* coincidence (Hale & Keyser, 1997, Mateu, 2000). We have, then, two categories so far, one conceptual, the other, procedural: N and P respectively. Further up on the structure, a spatial relation between two entities is a static *event*, and we have thus derived *uncaused verbs* (i.e., *Unaccusative V*). Different kinds of unaccusative Vs arise when varying the nature of the P node: telic and atelic, static and dynamic unaccusative Vs. The most complex structures appear when the *event* has an external initiator, which requires the presence of a *cause* primitive. We have now *caused events*, which may or may not include a spatial relation: (Di)*Transitive* and *Unergative* verbs. Having this conceptual (pre-linguistic) skeleton, we can fill the places with the available information, participants, time, place, etc. Let us illustrate the aforementioned structures:



1.3 <u>Two different kinds of systems:</u>

In this section we would like to make a distinction that we consider essential when building a theory about the mind: the distinction between *Generative systems* and *Interpretative systems*. This distinction is not only terminological, but has major consequences to the theory of QHC since we will demonstrate that only *certain systems* allow elements in their *quantum state* (i.e., comprising all possible outcomes), which, following Schrödinger (1935), we will call the *ψ-state*.

a) *Generative Systems*: Generation equals *Merge*, a free, unbounded, blind operation that takes elements sharing either *ontological* or *structural* format[2] and puts them together. For example, the syntactic component, the arithmetical capacity, the musical capacity and the pre-syntactic instance of the conceptual-intentional system.

[2] See Krivochen (2011a) for an analysis of both. A brief definition is the following (Krivochen, 2011a: 17): "(…) *Ontological format refers to the nature of the entities involved. For example, Merge can apply ("ergatively", as nobody / nothing "applies Merge" agentively) conceptual addresses (i.e., roots) because they are all linguistic instantiations of generic concepts. With ontological format we want to acknowledge the fact that a root and a generic concept cannot merge, for example. It is specially useful if we want to explain in simple terms why Merge cannot apply cross-modularly: ontological format is part of the legibility conditions of individual modules.*
Structural format, on the other hand, refers to the way in which elements are organized. If what we have said so far is correct, then only binary-branched hierarchical structures are allowed in human mind. The arguments are conceptual rather than empirical, and we have already reviewed them: Merge optimally operates with the smallest non-trivial number of objects. Needless to say, given the fact that ontological format is a necessary condition for Merge to apply (principled because of interface conditions, whatever module we want to consider), the resultant structures will always consist on formally identical objects (…)"

b) *Interpretative Systems*: Interface systems, they have to read structural configuration build up by generative systems. For example, the sensory-motor system and Relevance Theory's inferential module (the post-syntactic instance of the conceptual-intentional system).

An essential difference is that, as Generative systems are blind to anything but format, they can manipulate objects in their ψ-state and transfer them to the interface systems (to which we will come back later). ***Transfer and interpretation is Heisemberg's observation or opening "Schrödinger's box": a structural relation between an element in its ψ-state and a procedural element / logical unit with specific characteristics collapses the quantum state onto one of the possible outcomes.*** Let us go back to *Figure 1*: if we had to identify the areas in the figure with the modules involved in linguistic processing, the indeterminacy area (signaled by **?**) would be the syntactic working area, where elements enter in their ψ-state and are blindly manipulated, merged together and transferred to the interface levels, where structural configurations determine unambiguous interpretations in terms of outcomes. The interfaces can "peer into" syntax, to make sure a syntactic object (or any symbolic representation, for that matter) is transferrable: this is what we call the operation "*Analyze*". A typical derivation, then, would have three steps, which occur cyclically:

a) Narrow Syntax: *Merge* $\{\alpha, \beta_{[\psi]}\}$ This Merger collapses the quantum dimension on β for interface purposes.

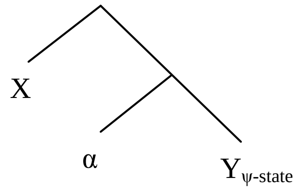
b) Conceptual Intentional System: *Label*[3] $\{\alpha, \{\alpha, \beta_{[D]}\}\}$

c) C-I: *Analyze*: is $\{\alpha, \{\alpha, \beta_{[D]}\}\}$ fully interpretable? That is, are all of its elements fully legible / usable by the relevant interface?

These three steps are obligatory, but there is a fourth step that depends on the result of *Analyze*: if affirmative, then the structure is *Transferred* to the module that has analyzed it, performing the necessary modifications according to the legibility conditions of this module (see the *Conservation Principle* below).

A note is in order here: an optimal design would require as many specific procedural instructions as possible outcomes of the manipulated units, in order to have *unambiguous interpretations at the interfaces*, regardless the two systems involved. The structural configuration required would be the following:

[3] We will not discuss the labeling algorithm here, as we have done extensive work on that elsewhere. We refer the reader to Krivochen (2011a, c) for discussion.



Let us assume that X is a procedural node, and α is an *n* number of non-intervenient nodes for collapse purposes. The relation between X and Y is still *local*, regardless of the number of branches in between: we care about distance in terms of Minimality (Rizzi, 2002), not in terms of number of branches. The ψ-state of Y is generally expressed in the form of an unvalued *feature*, a theoretical entity that exists in most grammatical models, not only Generative Grammar. We will try to de-construct the feature system and introduce the notion of *quantum dimension* and point out its advantages as it can account for the quantum properties of the human mind, taking Salmani-Nodoushan's (2008) global proposal further, in an attempt to develop a theory of the Quantum mind, with special focus on Language.

2. Radical Minimalism: Towards a model of Quantum Linguistics:

Our case for Quantum Linguistics will begin with an analysis of Transfer. *Transfer* is the operation that takes a given piece of information and sends it to another module or faculty. The transfer to the SM component is what used to be called *Spell-Out*, or *vocabulary insertion* in a Distributed Morphology framework. In a *massively modular* mind (Sperber, 2005, Carruthers, 2007), *Transfer* is essential in the interaction between modules. In Krivochen (2010b) we have differentiated *transfer* from *transduction*, taking the former to be the transmission of legible information from one module to another, and the latter to be the translation of information coming from the *phenomenological world* to a given *vertical faculty*, in Fodor's terms. In that paper we also said that as soon as a fully interpretable object (in terms of the interface levels, whatever these are) is assembled in a given level, it is transferred, thus leading us to a non-stipulative definition of *phase*:

P is a ***phase in*** $\boldsymbol{L_X}$ *iff it is the* ***minimal term fully interpretable in*** $\boldsymbol{L_{X+1}}$

This definition is *dynamic* and presupposes a strongly componential architecture, in which the components can *look ahead* to the legibility conditions of the module to which they have to transfer information, in order to do so in a legible format. Information is taken to be carried in the form of features (Chomsky, 1995), be them phonological, semantic or syntactic. These features are, according to Uriagereka's definition, "valued dimensions" of the form [+/- D], being D a given *dimension* and two possible values, + and -. That is the canonical representation of features and the one we will use for the purposes of the present discussion[4]. Within the Minimalist framework, features were fundamentally divided (Chomsky, 1995) in *interpretable* and *uninterpretable* on the one hand and *valued* and *unvalued* (when entering the derivation) on the other. A feature was not (un-)interpretable *per se,* but depending on the category it was part of. The logics were the following: if a feature F makes a *semantic contribution* in a LI, it is *interpretable* in that LI. Thus, [φ-features] were uninterpretable in T, but interpretable in nominals since [person / number / gender] are (allegedly) semantically interpretable in DPs, and it is the verb that agrees with the noun, and not the other way around. Of course that reasoning is wrong, since (a) there is no definition of "semantic contribution", and (b) if by "semantic contribution" we take "contribution to the explicature" (*decoding* and *referent assignment*), we are in serious trouble since φ-features in nominals, for example, are sometimes tricky, like in the case of *pluralia tantum*. Realizing this mistake, Chomsky (1999) changes the angle and entertains the idea that *uninterpretable* features enter the derivation *unvalued* from the *lexicon*. In his view, syntax only cares about valuation, not interpretability. However, we also find problems with this proposal. To begin with, the stipulative character of the assignment of valued and unvalued features to different categories is maintained. Besides, it is a clearly syntacticocentric solution, with no attention drawn to the interface levels and interpretability in the external systems. Unvalued features must be valued by *agree* between a *probe* and a *goal* in order to assure *convergence*. Once valued, the uninterpretable features are eliminated, by means of erasure. Interpretable information, on the other hand, is conserved, since it makes a "semantic contribution", whatever that means. Lasnik, Uriagereka & Boeckx (2005) borrow *Conservation Principle* from physics, and state the following law:

1st Conservation Law (Lasnik, Uriagereka & Boeckx's version):

All information in a syntactic derivation comes from the lexicon and interpretable lexical information cannot be destroyed.

The problem with this law is that it makes use of lexical information taken from a pre-syntactic and monolithic lexicon, which is the norm in orthodox Minimalism, but with which we will not work. However, keep in mind the spirit of the principle, since we will try to "recycle" it later. They go further away, positing a second conservation rule, applying to *interpretable structures*[5]:

2nd Conservation Law:

Interpretable structural units created in a syntactic derivation cannot be altered.

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[4] For details, see Adger (2008) and Adger & Sevenoius (2010).

[5] This principle is reminiscent of Edmond's *Structure Preserving Hypothesis,* but the mention of *interpretability* gives it a more "minimalist flavor".

Given our definition of *phase,* we can understand what they mean by "interpretable structural units", in fact, one could easily replace that in our definition without any significant loss of meaning. But we will try to introduce a radical change in the way derivations are seen. For that purpose, we modify a bit the conservation laws to fit our presentational purposes:

First formulation of the Conservation Principle (our formulation):

a) *Interpretable information cannot be eliminated, it must go all-the-way through the derivation*

b) *Uninterpretable information is "viral" to the system and must thus be eliminated by Agree*

In this formulation we expect to be covering and summarizing the meaning that both Chomsky and Lasnik et. al. wanted to convey ("viral" theory of uninterpretable features is Uriagereka's).
After having presented all this information, there is still a basic question to be addressed: what is really the difference between interpretable and uninterpretable features? Or, to be a bit more radical: are there *uninterpretable features* at all? Notice that the difference between interpretable-uninterpretable, although subsumed to that between valued and unvalued, is still there at the very core of the theory, and is taken as a primitive, with no explanation whatsoever. If syntax only cares about putting things together, why should it bother about valuation and so on? After all, *feature valuation is an operation that only makes sense taking convergence at the interface levels into account, but in the syntax proper* (or "narrow syntax") *it is perfectly superfluous*, since nothing "converges" or "crashes" in the syntax.

What we propose regarding all so-called "uninterpretable features" is that they ***do not exist at all***, especially considering the proposal made in Chomsky (1999) that *uninterpretability* is concomitant to *unvaluation*. That would be the strong (and optimal) thesis. Instead of a number of features (number that has increased over the years) which enter the derivation valued or unvalued depending on the category they compose, we have a minimal number of ***quantum dimensions*** conveying semantic (conceptual or procedural) meaning, which adopt one value or another in a *local relation* with a proper procedural head, namely, a *Minimal Configuration* (Rizzi, 2004). Let us analyze what we mean by *quantum dimensions*. Chomsky's feature valuation process needs:

a) A *probe*, an *unvalued* dimension in a (functional) head

b) A *goal*, the *same* dimension but *valued* in a c-commanded head[6]

[6] The relation is always head-head, even if we say that T matches features with a DP, it is really matching features with D, and all subsequent operations (e.g., movement) apply to the smallest term that assures convergence, namely, the whole DP.

We see a redundancy here, since we will depart from the claim that there is no need for the same dimension to be in two heads just for the sake of feature valuation, the arguments in favor of these operations become cyclical[7]. Our argument seeks to eliminate *Agree* both as a relation and as an operation. If the system is really "free", as Boeckx (2010) claims, then there cannot be any "Agree" operation as currently formulated since it would imply a complication for the theory and a restriction for the possible relations between elements (namely, relations are limited to those between *probe* and *goal*). A constructivist theory needs *Agree* in order to establish the "right" (i.e., convergent) relations between elements, but in our theory, based on *licensing*, such a restriction is regarded as stipulative.

Our claim here will be that language is part of the natural world, and as such, it is a system whose physical properties are the same as any other system. We will invoke here Heisemberg's (1927) *indeterminacy principle*, which can be better explained from an example:

Imagine we have an electron in a tridimensional space, and we want to know its location. In order to do so, we need to see it, projecting some kind of light on it. This light is projected in the form of a *photon*, a particle with mass. The "problem" is that when the photon crashes with the electron, there is a change in the original location, which remains unknown. That original location (we have taken this magnitude just for the sake of the example, but we could have also worked with speed or trajectory) is taken to be a "superposition" of all possible locations, expressed in the form of a "*wave function*" (in de Broglie's terms). Therefore, there will always be a magnitude whose real value will remain unknown to us. In this kind of physical systems, it is the ***observation*** that makes the relevant dimension *collapse* to one of the possible states[8]. *Indeterminacy is a natural characteristic of physical systems, and by no means an instrumental problem*, taking physical system in its technical sense, that is, any portion of the physical universe chosen for analysis. We take "physical universe" to be equivalent to "natural world", and we will use one or the other indistinctly. Magnitudes (or *dimensions*, to maintain a term more closely related to linguistics, since we are not dealing with measurable elements) are *not* necessarily binary; what is more, *in abstracto* they can comprise as many states as the system requires, which, as we will show later, leads us to a much simpler form of minimalism. ***We will express it by using this notation: for any dimension D, [D_X] expresses its quantum state.***

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[7] If we take an architecture like the one outlined in Krivochen (2010b), we would first have a "fully interpretable" RSS and then we would add (un-interpretable) features that would be later on valuated by Agree and erased from the computation (see Epstein & Seeley, 2002, for a discussion on this specific point). That is, for us, a redundant (and stipulative) computation, and plainly inadmissible in a Radically Minimalist theory.

[8] See, for example, the well-known EPR (Einstein-Podolsky-Rosen) paradox, which inspired Schrödinger (1935) paper.

Let us suppose that we have a physical system which starts out in a state α, and changes, over some time, into state α'. Of course, it could have started out in any of many *different* states. So suppose it starts out in state β, and changes over the same considered time interval into state β'. We can schematically represent these two possible "trajectories" like this:

i) $\alpha \rightarrow \alpha'$

ii) $\beta \rightarrow \beta'$

Since α and β are possible states of the system, so is their arbitrary linear combination **aα + bβ**. What ***Schrödinger's Equation (SE)*** tells us is that given that α and β would change in the ways just indicated, their linear combination must also change in the following way:

iii) $\mathbf{a}\alpha + \mathbf{b}\beta \longrightarrow \mathbf{a}\alpha' + \mathbf{b}\beta'$**.**

The interesting fact about the above mentioned equations is that *they hold only if no "measurement" is taking place.*

If a "measurement" (say, mere observation) is taking place then we must consider an entirely different story about how the state of the system changes: during the measurement, the system S must "*collapse*" into a state that is certain to produce the observed result of the measurement. The hypothesis is exemplified by Schrödinger (1935) using the now famous "cat paradox", which deserves to be quoted in full-length:

> *"A cat is penned up in a steel chamber, along with the following device (which must be secured against direct interference by the cat): in a Geiger counter there is a tiny bit of radioactive substance, so small, that perhaps in the course of the hour one of the atoms decays, but also, with equal probability, perhaps none; if it happens, the counter tube discharges and through a relay releases a hammer which shatters a small flask of hydrocyanic acid. If one has left this entire system to itself for an hour, one would say that the cat still lives if meanwhile no atom has decayed. The ψ-function of the entire system would express this by having in it the living and dead cat (pardon the expression) mixed or smeared out in equal parts. It is typical of these cases that an indeterminacy originally restricted to the atomic domain becomes transformed into macroscopic indeterminacy, which can then be* ***resolved*** *by direct observation*". (p. 7-8. Highlighted in the original)

The question to be asked now is: *how do we apply this to language?*

Our answer will be the following: ***we will consider language to be a physical system, and therefore, if SE applies to any physical system, it must also apply to language***. Of course, we are not saying that language shares all of its features with other systems (since, as Boeckx correctly points out, we may have one or the other scattered in different systems), but it must be considered fundamentally as a physical system if we take seriously the idea that it is part of the natural world, as Chomsky has explicitly done along the years. We must say in this point that, despite what it may seem[9], there is no *reductionism* in treating FL as a physical system if we consider that a ***physical system*** is merely *the portion of the universe taken for analysis*. If we consider that universe to be the so-called "natural world", then, our thesis follows naturally. That is, we are not making a reduction of biology to physics, but simply analyzing a *biological* phenomenon in physical terms, as a physical system (in which there is no contradiction whatsoever) and, as such, applying the *tools* that have been devised in physics in the degree that it is possible, and without confusing the *methodological* tools with *substantive* elements. Of course, looking for exact correlates between *any* two fields would be irrational in the *substantive* level (i.e, units of analysis, as Poppel & Embick, 2005 correctly point out), but we put forth that the *methodological level* has much to tell us, as we are all working with "parcels" of the same Universe that, we will try to show, are ***identical in a principled level of abstraction***.

The next step would be to put this theory in practice. Let us assume the following quantum dimension: [Case_X]. Following the idea presented in Krivochen (2010c), this dimension comprises three possible “outcomes”: NOM sphere (φ), ACC sphere (θ) and DAT sphere (λ). All three are possible final states of the system, and therefore the linear combination must also be considered a legitimate state of the system. The dimension *in abstracto* could then be expressed as follows, using SE:

iv) $N\varphi + A\theta + D\lambda$

As we have said before, this only holds if no “measurement” takes place, in Schrödinger’s terms. We will not speak of “measurement”, since Case is not a magnitude, but we will consider that the factor that makes the relevant dimension collapse is ***the merger of a functional / procedural head*** in a local relation with the dimension, relation that is read out in the LF interface level. What we must take into account is that not only do we have DPs with [Case] and functional heads in interaction in the computational system, but the output (i.e, the resultant state) should optimally converge at the interface levels, so our problem is a bit more complicated. As usual, we will focus ourselves in the C-I component. What we want to do now is derive the relations P-DAT; *v*-ACC and T-NOM from interface conditions, apart from the argumentation we have made in Krivochen (2010c) in relation with θ-roles and Case, to which we refer the reader. Anything else would be stipulative, and that is something we cannot accept in Radical Minimalism.

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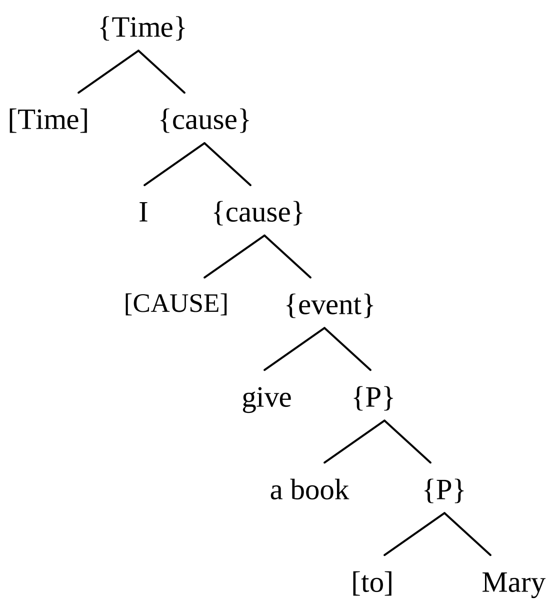
[9] We thank Phoevos Panagiotidis (p.c.) for making this objection, and other valuable comments as well.

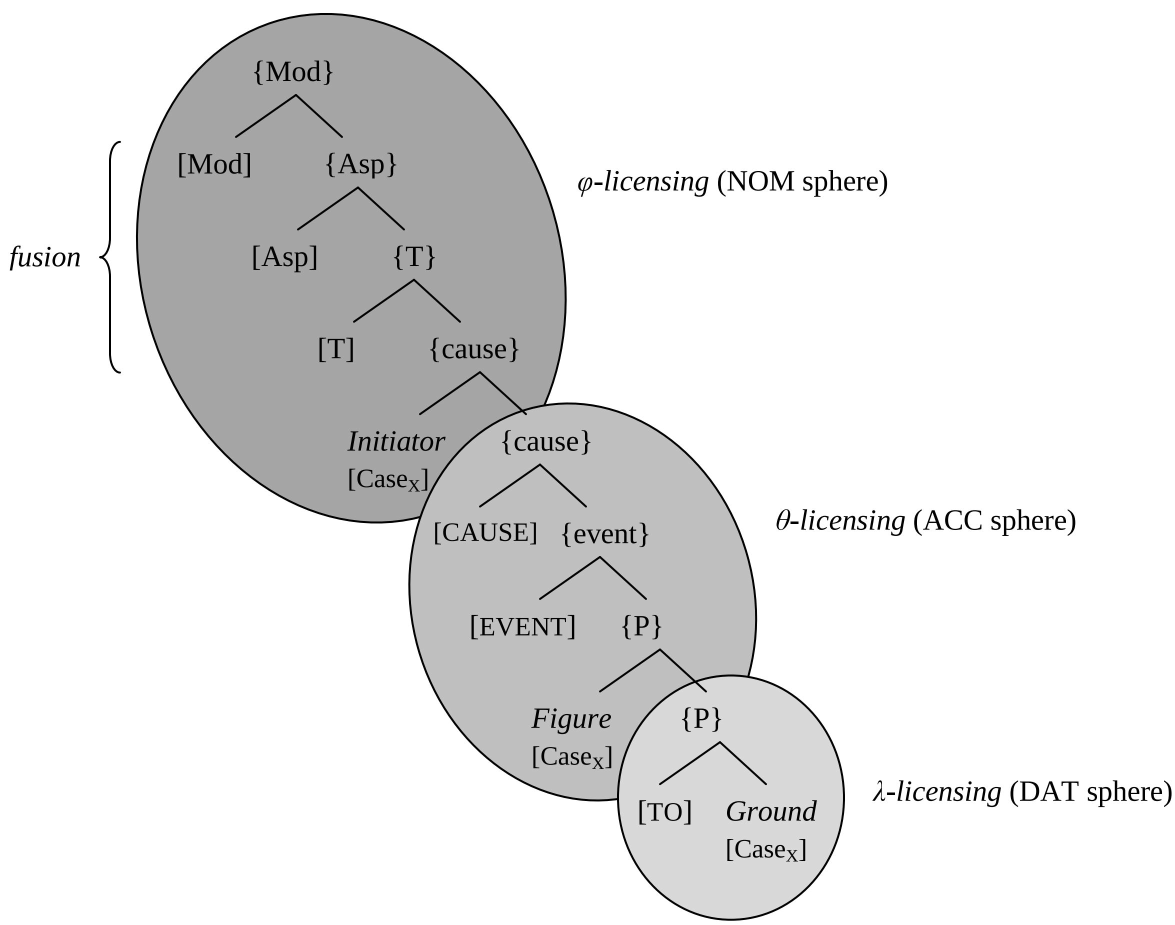
Epistemologically, we have the advantage over theoretical physics that we have observable stretches of language where to test our hypothesis. So, let us take a ditransitive *Prepositional Indirect Object Construction* (PIOC):

v) I_{NOM} gave a book_{ACC} to Mary_{DAT}

By looking at the same construction in other languages with rich casual morphology (like Latin, Sanskrit or Greek) it has been established that the DP [I] has Nominative Case, [the book] has Accusative Case and [to Mary] has Dative Case. But this is nothing more than a description, with no explanation as to why things are the way they are. We will not review the classic attempts of explanation, but go directly to our point. The (LF) structural configuration for (v) is the following (omitting irrelevant positions / projections):



By hypothesis, each DP will bear a dimension $[\text{Case}_X]$, whose value when entering the derivation will be a "ψ-function", or a complex vector [Nφ + Aθ + Dλ]. That is, the quantum dimension will comprise all three possible values, as all three are possible states of the Case system for a particular DP. However, $[\text{D}_X]$ cannot be read by the interface levels, so the quantum dimension must "collapse" to one of the possible states. Here, it is not "measurement" but *Merge* that does the work. Let us take the {P} structure as an example. We have the merger of $\{\text{to}_{[\text{TO}]}, \text{Mary}_{[\text{Case}_X]}\}$. At this point in the derivation, we are already in condition of collapsing the quantum dimension in [Mary], since we have a *procedural head* in a minimal configuration that can license that dimension in a c-commanded XP (adapting the idea from Rizzi, 2004). This minimal configuration is defined in our terms *within phase boundaries*, following the definition given above. Since the procedural information conveyed by P is essentially *locative*, the quantum case dimension on [Mary] will collapse to the locative sphere, i.e., Dative. The licensing takes place only if there is no closer functional / procedural head that can license the relevant feature, in order to respect Minimality. Just as we have taken SE and Heisemberg's indeterminacy principle from quantum mechanics, we can also draw another principle, this time from *field theory* (Lasnik, Uriagereka & Boeckx quote this principle from fluid mechanics, but it is the same principle, as we are ***always*** dealing with physical systems): ***Locality***. Just like a particle cannot influence any other than its surrounding particles, a procedural head has a certain area of influence where it can license features if necessary. Remember that there is no checking / matching, so neither *greed* nor "enlightened self interest" are involved. It is interesting that influence can be indirect, that is, a particle α may not be able to influence particle γ since particle β is "in the middle", but by influencing β, α will have an effect on γ. That is what we call compositionality, in linguistics. The type of information that each domain carries in the form of dimensions is what makes the quantum dimensions in the arguments collapse, let us analyze this in a tree diagram (including labels only for clarity purposes):



Notice that the procedural / functional heads P, {cause} and the *Split TP* signal *quantum feature collapse areas*, in consonance with Minimality. Optimally, all quantum dimensions on a certain element should collapse within the minimal collapse area (or informational domain, as we have said above). The three Case spheres, as we have already said in Krivochen (2010a), are in correlation with the Thematic spheres, following DeLancey's (2001) proposal. Projections are completely irrelevant, but we have included labels for the sake of clarity. Each circle determines the boundaries of a domain of information in terms of LF, the *locus* of collapsing. Collapsing cannot take place across boundaries for two reasons: first, because of the Earliness Principle: operations take place as soon as they can, and there is no reason to wait for another functional head to merge when we already have a head that can make the quantum dimension collapse. Second, because of Minimality: *different types of informational domains are like different perspectives for measurement, they make the dimension collapse to one state or the other*. The difference with physics here is that there is a correlation between the information carried by the functional head and the state it licenses, interface-determined. Notice also that it would make no sense to talk about "VP" or anything like that, since VP presupposes a root already categorized, and we posit that category, like Case, is a quantum dimension and that it collapses in a local relation with a procedural head, the result being read off in the interface levels.

Now we have to justify the presence of the primitive dimensions [CAUSE], [EVENT] and [LOCATION] in the syntax, which seem to have been carried from earlier stages, if we follow the architecture we have proposed in Krivochen (2010b). In order to do this, we would need to reformulate the conservation principle, now that we have dispensed with features as they were traditionally conceived and any attempt of "valuation" process:

Revised formulation of the Conservation Principle:

a) *Dimensions cannot be eliminated, but they must be instantiated in such a way that they can be read by the relevant level so that the information they convey is preserved.*

This means that, if those dimensions are present in a pre-linguistic conceptual instance, they have to be carried all throughout the derivational path, so that no information is lost. From a purely biological / physical point of view, if information is energy (i.e., electrical stimuli), then eliminating information equals eliminating energy, which is not possible as energy can be *transformed*, but neither *created* nor *destroyed*. The Conservation Principle allows us to sketch a holistic theory of the mind, without focusing on one isolated component, but taking into account the interfaces with other mental systems and the conditions that have to be fulfilled. It both constraints and offers a set of possibilities for instantiation.

3. Conclusion:

In this section we would like to review some of the basic tenets of Radical Minimalism, which we take to be compatible with any form of Quantum Linguistics:

1. Language is part of the "natural world"; therefore, it is fundamentally a *physical system*.

2. As a consequence of 1, it shares the basic properties of physical systems and the same principles can be applied, the only difference being the properties of the elements that are manipulated in the relevant system.

3. The operations are taken to be very basic, simple and universal, as well as the constraints upon them, which are determined by the interaction with other systems, not by stipulative intra-theoretical filters.

4. 2 and 3 can be summarized as follows:

   Strong Radically Minimalist thesis (SRMT):

   All differences between physical systems are "superficial" and rely only on the characteristics of their basic units [i.e., the elements that are manipulated], *which require minimal adjustments in the* ***formulation*** *of operations and constraints* [that is, only notational issues]. *At a* ***principled level****, all physical systems are identical, make use of the same operations and respond to the same principles.*

We have tried to present some aspects of Salmani-Nodoushan's (2008) proposal, and connect them with our own Radical Minimalism. We have seen that there are very interesting connections between both approaches, and hope this work helps this new field of ***Quantum Linguistics*** grow with the cooperation of linguists, physicists, biologists and mathematicians. Only by building bridges across disciplines can we expect to gain some insight into the most complex and fascinating object in the natural world: the human mind-brain. Whether this enterprise will succeed, only time can tell.

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