6 Third Factors in Language Design: Some Suggestions from Quantum Field Theory

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Naturally, one seeks the simplest account of U[niversal] G[rammar]. One reason is just normal science: it has long been understood that simplicity of theory is essentially the same as depth of explanation. (Chomsky 2015)

Now in the further advancement of science, we want more than just a formula. First we have an observation, then we have numbers that we measure, then we have a law which summarizes all the numbers. But the real glory of science is that we can find a way of thinking such that the law is evident. (Feynman 1963)

The simplest conclusion, then, would be that Merge applies freely. A labeling algorithm, keeping to minimal search, assigns labels to expressions {X, Y} constructed by iterated Merge (external EM or internal IM); labeling yields no new category . . . Operations can be free, with the outcome evaluated at the phase level for transfer and interpretation at the interfaces. (Chomsky 2015)

In 1949, Dick Feynman told me about his "sum over histories" version of quantum mechanics. "The electron does anything it likes," he said. "It goes in any direction at any speed, forward or backward in time, however it likes, and then you add up the amplitudes and it gives you the wave function." I said to him, "You are crazy." But he wasn't. (Dyson 1980)

1 Introduction

In a recent, nontechnical reflection on language in the framework of Generative Grammar (GG), Chomsky so characterizes the Basic Property of language:

Basic Property: each language provides an unbounded array of hierarchically structured expressions that receive interpretations at two interfaces, sensory-motor for

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externalization and conceptual-intentional for mental processes . . . At the very least, then, each language incorporates a computational procedure satisfying the Basic Property. Therefore, a theory of the language is by definition a generative grammar, and each language is what is called in technical terms an I-language – "I" standing for internal, individual, and intensional: we are interested in discovering the actual computational procedure, not some set of objects it enumerates, what it "strongly generates" in technical terms, loosely analogous to the proofs generated by an axiom system. (Chomsky 2013c: 647)

He then adds:

Naturally we seek the simplest account of the Basic Property, the theory with fewest arbitrary stipulations – each of which is, furthermore, a barrier to some eventual account of origin of language. And we ask how far this resort to standard scientific method will carry us. (656)

Concluding, he then remarks that

insofar as the surmise is sustainable, we would have an answer to questions about apparent optimal design of language: that is what would be expected under the postulated circumstances, with no selectional or other pressures operating, so the emerging system should just follow laws of nature, in this case the principles of Minimal Computation – rather the way a snowflake forms. (662).

This chapter suggests some specific "laws of nature" that are, we think, uniquely apt to explain the fundamental properties of language – namely, the emergence of the Fibonacci series, unrestricted Merge, labeling at the interface with the conceptual-intentional system, copy plus deletion, syntactic Phases (Chomsky 2017), semantic compositionality, an internalist semantics, and the derivation of Logical Forms. They are extracted from the basic principles of Quantum Field Theory (QFT), that is, the modern physics covering also macroscopic objects at room temperature. We will introduce this domain briefly and simply. Here we will concentrate only on the emergence of the Fibonacci series and the derivation of Logical Forms. For a more complete and detailed analysis of all these parallelisms, see (Piattelli-Palmarini and Vitiello 2015) (hereafter PPV).

An introduction to quantum physics might start (Zee 2010) with an idea of Richard Feynman's (Feynman and Hibbs 1965): basically "the sum of all histories" in the quote at the opening of this chapter. Feynman refers to the fact that in quantum mechanics, the trajectory a particle follows cannot be uniquely defined. One may think only in terms of a bunch of trajectories, or histories – in technical jargon, "path integrals." The computational problem consists in finding out where at a given time the particle will arrive with the highest probability, traveling through its mysterious but possible paths.

We introduce this story because there seems to us to be an interesting parallel between Feynman's sum of all histories and Chomsky's unrestricted Merge.

The idea that a particle does anything it pleases, goes anywhere, forward or backward in time, until one computes the so-called path integral under the constraint of minimal action, is a close parallel (we think) to Chomsky's suggestion that the most elementary syntactic operation (recursive binary Merge) operates totally freely until it interfaces with the interpretive apparatus, where it meets the constraints of minimal computation and strict locality. As we will see in what follows, the collapse of all possible paths onto the highest probability of the arrival of a particle, when it interacts with the macroscopic measurement apparatus, resembles the way in which free Merge yields structure, labeling, and meaning only at the interface with the conceptual-intentional system (CI). We suggest that QFT may make sense of this further transition to a bare economy of factors in syntax. Moreover, Feynman's emphasis on the ultimate "evidence" of physical laws parallels Chomsky's emphasis on simplicity and/as depth of explanation.

In the PPV paper, we show how the Minimalist Program (MP) and QFT share a number of mathematical aspects at a deep level of their respective formulations. Here we restrict this analysis to two main issues. First we show how the X-bar tree arises from recursive applications of binary Merge, generated by simple algebraic rules in QFT, then that concepts or meanings, emerging out of the syntactic derivation, find their description in terms of collective modes in the dynamical process of the rearrangement of symmetry in QFT, forming the "manifold of concepts" (of Logical Forms (LF) in older nomenclature, the Conceptual-Intentional interface in the new).

Thus, in spite of the fact that at first sight nothing would seem more alien to a linguist's interests and expertise than QFT, we are going to try to show that these apparently distant fields of inquiry have, deep down, a lot in common, especially within the framework of the current Minimalist Program with its Strong Minimalist Thesis (SMT). If plausible, our effort underscores Galileo's principle that nature is simple.[1] In order to make our discussion transparent for the reader not familiar with QFT formalism, we avoid mathematical technicalities. The interested reader may find formal details in PPV.

This is the plan. In Section 2, we briefly discuss the role of the binary recursive structure of the X-bar tree and some aspects of QFT with reference to linguistic structures. This leads us to one of the main results of our discussion – namely, we establish a relation between the algebra of binary matrices in QFT and the generation of X-bar trees and their Fibonacci progression for the number of branches. In Section 3, we show that coherent condensates of collective modes in QFT lead to the formation of a "manifold of

[1] See Epstein et al. 2012 and Chapter 2, this volume.

concepts" corresponding to Logical Forms in linguistics. In Section 4, we discuss doubling the degrees of freedom in QFT and argue that this underlies the relation of pronounced to unpronounced copies in linguistics, thereby providing a "built-in" dynamic reference that is not imported from external environments, making the general computational structure self-contained. We point out that the power of this linguistic tool resides in such a "self-consistency." We simply mention here (see PPV for details) the irreversibility of time evolution (breakdown of time-reversal symmetry), anti-commutativity, self-similarity, and more. The Wrap-up Section is devoted to conclusions. In the Appendix, we comment on the Labeling Algorithm in linguistics. We believe that it should then come as no surprise that interesting formalisms and germane ideas can come to linguistics from QFT.

2 Binary States All the Way

In Generative Grammar (GG), by long tradition, we have a collection of binary entities. It is well known that syntactic trees have only binary branching. Lexical items are represented, by useful convention, as (+/−). For just two instances: nouns are (+N, −V), verbs as (−N,+V). This notation can be straightforwardly extended to Phrasal Heads (+H, −C) and Complements (−H,+C). In syntactic derivations, we have Terminal nodes (+T) and nonterminal nodes (−T). Copies of lexical items in a sentence can be pronounced (+Pr) or unpronounced (−Pr). Recursive applications of Merge may or may not produce a Phase (we will return to the notion of Phase in what follows).

Unified Merge (also called simply Merge) generates a binary set, extracting two items from a workspace that includes everything already generated and the lexicon. It yields {α, β} (Piattelli-Palmarini and Uriagereka 2008) with no label, no projection, no linear order, and independently of the categories of α and β. Merge does not overtly encode a label, such as N or V. At the Conceptual-Intentional interface, however, all syntactic objects (SOs) must be interpreted, so labels are needed. There must, then, be a Labeling Algorithm (LA) that introduces them. Some of Chomsky's latest technical papers (2013a, 2015; see also Appendix) concern the nature and *modus operandi* of this algorithm. He proposes: "[LA operates under] just minimal search, presumably appropriating a third factor principle, as in Agree and other operations." We suggest here some third factor principles derived from QFT that Narrow Syntax (NS) and its interfaces with the Conceptual-Intentional (CI) and Sensory-Motor (S-M) systems may have "appropriated." If this is the case, these physical principles and their simple formalism validate, we think, Chomsky's statement that "simplicity of theory is essentially the same as depth of explanation."

2.1 Why Quantum Field Theory?

QFT is not limited to the microscopic universe of photons, electrons, and elementary particles; it encompasses macroscopic manifestations of quantum physics at ordinary temperatures. Examples of "macroscopic quantum systems" are superconductors, ferromagnets, crystals, and in general systems presenting ordered patterns. These systems exhibit coherence over macroscopically large distances that are extraordinarily robust against environmental perturbations, as shown by their extremely long-lived existence in a wide range of temperatures (very low for superconductors; of several thousands of centigrade degrees for crystals; the diamond, e.g., melts (loses its coherence) at a temperature of about +3545°C). These systems are explained with great accuracy by QFT (Alfinito, Viglione, and Vitiello 2001; Blasone, Jizba, and Vitiello 2011; Umezawa 1993). Moreover, in QFT observed deviations from exact symmetry (*symmetry breakdown*) are the result of an underlying dynamics. These changes are due to a mechanism of *dynamical rearrangement of the symmetry.* Vitiello (2001) has an extended qualitative description of these and other features of QFT.[2]

2.2 Binary Matrices in QFT and the X-bar Tree Generation

As mentioned earlier, in GG we have several binary entities that can exist in one of two possible states. We think, therefore, that a binary notation can be used successfully. In QFT, one starts with a minimal (irreducible) set of operators (typically matrices) and the space of the states, described by vectors on which the operators are defined. Any operator in the theory is then obtained from the operators in the minimal set and the unit operator. In the present case, we assume that any operator is made of the set of three 2×2 matrices, called Pauli matrices; also sigma matrices, σ^+, σ^-, and σ_3; and the unit matrix I.

The state space is built on the basis of the states designated as $|0\rangle$ and $|1\rangle$. The $|0\rangle$ state is considered to be the "ground" state, while $|1\rangle$ is the "excited" state. The transitions between the two states $|0\rangle$ and $|1\rangle$ are represented by simple multiplication relations involving the state vectors and the sigma matrices, or combinations of these. Repeated applications of the (sigma) matrices generate an "action" dynamic, a multiplicity of vectors, each in one

[2] Borrowing a fine example from the Oxford particle physicist Frank Close (Close 2011), let's imagine a formal dinner, with a very large round table, such that each guest has a napkin to his/her right and one to his/her left and cannot decide which one to pick. There is symmetry between left and right. Then a bold guest decides to pick the one on his/her right. This action breaks the left/right symmetry. Each guest can only see what the immediate neighbors do. Consequently, a "wave" of right-picking napkins travels along the table. There is a wave of symmetry breaking, without any transport of matter. This wave is the analog of a massless Nambu-Goldstone boson (see Section 3).

of the two basic states. We will come back to the issue of ordering in a moment. It is not necessary to reproduce here the explicit form of the sigma matrices. It need only be observed that the basic transition operations induced by the σ^+ and σ^- are activation/inactivation, on/off, or in symbols:

$$\sigma^+|0\rangle = |1\rangle, \quad \sigma - |1\rangle = |0\rangle.$$

Moreover, application of σ^+ on the state $|1\rangle$ has the null effect, in symbols $\sigma^+|1\rangle = 0$, and similarly

$$\sigma^-|0\rangle = 0.$$[3]

With repeated step-by-step applications of the sigma transformations, branching points are generated, yielding a tree with nodes. This parallels linguistics' X-bar tree:

$$|0\rangle \rightarrow \sigma^+|0\rangle = |1\rangle \rightarrow \begin{cases} \nearrow \; \sigma^-|1\rangle = |0\rangle \\ \searrow \; \sigma^+\sigma^-|1\rangle = |1\rangle \end{cases}$$

with number of states: 1 1 2 and so on. We get in subsequent steps other branches and states such that the sequence 1 1 2 becomes 1 1 2 3 5 8 . . .; this is the Fibonacci (F) sequence, where each number in the progression is the sum of the two preceding ones. Thus, the sequence of the numbers of states at each step in our recursive procedure reproduces the F sequence. The sequence extends indefinitely, with any number of successive steps.

This result is important, because it parallels Chomsky's (Chomsky 2015) thesis that Merge is unconstrained, and that issues of labeling (headedness, categorization of lexical items) and ordering only arise at the interfaces of Narrow Syntax with the CI system and the SM system.

David Medeiros and Piattelli-Palmarini (Medeiros 2008, 2012; Medeiros and Piattelli-Palmarini 2016) demonstrated the generation of the Fibonacci progression as the number of nonterminal and terminal nodes in a syntactic tree. Various publications (see, e.g., Piattelli-Palmarini and Uriagereka 2008; Idsardi and Uriagereka 2009) showed the fundamental importance of Fibonacci patterns in language, from syllables all the way up to sentences.

Chomsky's pre-Minimalist approach to grammar (Government and Binding (GB); Chomsky 1981, 1982; Haegeman 1991) posited X-bar configurations as

[3] Simple as it is, the algebra of the sigma matrices is not at all trivial. The set of the transformations they induce has mathematical properties defining the so-called SU(2) group, which plays a crucial role in elementary particle physics and condensed matter physics. See Gilmore 1994; Wybourne 1974.

the fundamental recursive structure of syntax. It configured and organized "entities" such as Head, Complement, Specifier, First Projection, and Maximal Projection, displaying their all-important relations (e.g., the Specifier-Head relation). In Minimalism, these entities are considered redundant and are used only as expository devices. All the relevant properties and relations portrayed in the X-bar are now considered to be the straightforward result of recursive Merge. The generation of the X-bar tree via elemental steps as obtained earlier is in agreement with the SMT, where the X-bar tree is the result of recursive applications of binary Merge and is not part *as such* (we insist on this caveat: as such) of NS. The properties of X-bar and the Fibonacci series emerge from Merge and constraints imposed by the Conceptual-Intentional interface (see Medeiros 2008, 2012; Medeiros and Piattelli-Palmarini 2016).

2.3 The X-bar Tree, Time-Reversal Symmetry and Its Breakdown

In the QFT generation of the X-bar tree (the F tree) described earlier, knowledge of the state $|0\rangle$ or $|1\rangle$ at any given step of the tree is not sufficient for knowing its previous, parent state; we must also know which branch we are on. This is a direct consequence of the X-bar tree's self-similarity property: at any stage or step, the tree presents similar branching structure. The self-similarity property finds formal expression in the associated Fibonacci progression in the number of the states, as discussed. While the tree construction (the "way forward") is fully determined by sigma operations, the "way backward" is not uniquely determined by knowledge of the state $|0\rangle$ or $|1\rangle$. This emphasizes the importance of the "history" of syntactic derivations and the traditional notion of syntactic markers. Parameterizing by time the movement through an X-bar tree breaks time reversal symmetry. This feature of X-bar time irreversibility justifies the formal use, in linguistics, of concepts and notions typical of thermodynamic dissipative systems, such as, for example, thermal bath and entropy, which are also implied in the use of statistically based analysis (see (PPV) and Subsection 4.1.) Remarkably, the many-body scheme we propose is characterized by irreversible time evolution over the X-bar tree. Seminal work by Kayne (1994) demonstrated the necessity for syntax to break symmetric constructions. Andrea Moro (2000, 2013) (see also Chomsky 2013a, 2015) formulated a weaker version called dynamic antisymmetry suggesting that symmetric constructions are eliminated at the point of externalization. In NS, Merge is free to apply to symmetrical structures and generate symmetrical structures, provided that symmetry is broken at the relevant interface. Crucially, order and categorization (labeling) arise only at interfaces.

3 Dynamical Formation of Long-range Correlations: From Elementary Components to Ordered Patterns

So far we have considered one binary element, the two-state system (|0⟩, |1⟩). In QFT and in linguistics, we have a superposition of states, N states and N binary elements. Of these, let ℓ be in state |1⟩ and (N – ℓ) in state |0⟩. The sigma matrix σ_3 gives the difference between excited and unexcited states. Calculation gives the quantity (ℓ – N/2) (Umezawa 1993; Beige, Knight, and Vitiello 2005; Shah, Umezawa, and Vitiello 1974). This quantity is called the order parameter: in the QFT limit of large N (N >> ℓ), its being nonzero signals that the system exhibits an ordered pattern consisting in the fact that indeed no symmetry exists between the excited and unexcited states. This dynamical feature of spontaneously broken symmetry theories fits well with syntax where we need to deal with long-range correlations under conditions of strict locality and minimal computation. Let's for the moment understand "long-range" as a relation spanning more than one word.

Observed ordered patterns in condensed matter physics get their dynamical origin and stability from the coherent propagation of correlation waves through the system (for a simple analogy, see note 2; in QFT, the quanta associated to these correlation waves are called the Nambu-Goldstone (NG) quanta). One expresses this by saying that NG quanta get coherently condensed in a system's lowest energy state, also called ground state. Different densities of such NG condensates characterize observable physical properties, so that the system may have many ground states, each physically different in its properties from (in jargon, unitarily inequivalent to) the other ones. As a result, the space of the system states splits into (infinitely many) physically inequivalent "phases" (we use uppercase (Phases) for syntax and lowercase (phases) for physics). This is called the *foliation* process.

Summing up, ordered patterns are dynamically generated and change of scale from microscopic to macroscopic sets in. One refers to this amazing phenomenon as the *dynamical rearrangements of symmetry*[4] (Vitiello 1974): new observable properties appear as *system properties*, not belonging to a system's individual elementary components. For example, rigidity, electrical conductivity, and magnetization are properties of a metal, not of the electrons

[4] Simplifying rather drastically, the dynamical rearrangement of symmetry leads to a change of the algebra, that is, of the commutation relations of the system-characterizing operators. The commutation relations measure the "cost" of inverting the order of application of two operators. If we have zero, the two operators can be inverted without any change, if we have nonzero, the two operators cannot be inverted. In the case of language, we have perfect inversion (as in the French *bonnet blanc et blanc bonnet*, an expression used to signify that nothing has changed, in spite of appearances, and in copular sentences à la Moro: *John is the lawyer* / *the lawyer is John*); we have cases of impossibility of inversion (as in *the man* versus **man the*), or cases of inversion with change of meaning (as in the famous JFK speech: *what this country can do for you / what you can do for this country*).

and atoms comprising the metal – though, of course, the elementary components have their own properties determining the basic dynamics out of which the system properties *emerge*. These emerged properties are *collective* dynamical properties characterizing the macroscopic system. Order appears as a collective dynamical property of the system. In conclusion, QFT allows the quantitative, mathematically rigorous definition of *emergence* as a dynamical phenomenon. For the mathematical apparatus see (Umezawa 1993, Blasone, Jizba, and Vitiello 2011). For an extended qualitative presentation, see Vitiello (2001). As a result, we suggest, the concepts of phase in QFT and Phase in Minimalism are interestingly similar. We explain in what follows how this relates to the Strong Minimalist Thesis.

3.1 Condensates, the Manifold of Concepts, and Logical Forms

Thus, our system has undergone a formidable dynamical transition, moving from being a collection of elementary components (lexical items with the algebra of the sigma matrices σ^+, σ^-) to phases of collective, coherent condensate of $S^{\pm}$ fields. Our primary purpose at this point is to identify a specific conceptual, meaningful linguistic content (traditionally called a Logical Form (LF))[5] with a specific collective coherent phase. The LF, characterized by a compositionality of concepts or meanings (the "manifold of concepts"), thus emerges as a dynamical process out of the syntactic operations of merging and then labeling lexical items in a way similar to the one by which, in many-body physics, macroscopic system properties emerge as a coherent physical phase out of a collection of elementary components at a microscopic (atomistic) level.

We suggest that a compositionally organized unit of linguistic meaning (an LF) arises from a "continuous" potential domain of possible meanings by selecting one specific Phase from many "unitarily inequivalent" ones. The meaning of entire sentences emerges as a collective mode, not a result of mere associative processes that concatenate lexical items by a shallow linear procedure. The structure-dependent property of syntactic derivation finds here an interesting parallelism with QFT. Compositionality of meaning comes from "phase coherence" in language, as propositional units (the Complementizer Phase, CP) and units of predication (the complete verbal shells *v**P). In QFT, phase coherence arises from units whose carriers are the collective $S^{\pm}$ (the NG) boson fields. We also then come to understand why the issue of ordering becomes relevant only at the SM interface (cf. previous section).

5 For expository reasons, we continue adopting here the notion of LF, but in Minimalism this is just CI, the place where syntactic structure systematically connects with meanings.

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Order is lack of symmetry; it appears only when symmetry is broken. For the same reason, categorization, non-commutativity, and order are only necessary at the interfaces. Only the many-body limit CI needs labeled heads: which one is a verb, which one a noun, an adjective, and so on; formal construction through binary Merge does not require labeled structures (Noun, Verb, Adjective, Preposition, etc.). Labels (the Labeling Algorithm – see the Appendix) only arise at the interface with meaning. The conceptual-interpretive system at each Phase (CP, *v**P, (possibly also DP)[6]) needs labels for syntactic objects to trigger different interpretive modes.

In conclusion, the process of generation of meanings (the manifold of possible LFs) appears to be a collective dynamical phenomenon. We now have a quantitative characterization of the "interfaces" where Narrow Syntax contacts (interfaces with) the conceptual-intentional (CI) system: interfaces are where symmetry breaks down.

4 Reference and Truth-functional Semantics

Chomsky has on several occasions (see Chomsky 1986, 1995, 2013b; Chomsky and McGilvray 2012) and in private conversations with one of us (MPP) expressed serious doubts that linguistic expressions, notably including lexical items, actually have external referents in the outside world. Some lexical meanings apply to several possible external referents or to no referent at all.[7] Unlike the signals and vocalizations of animal communication, there is no unique correspondence between a word and an objective external referent. All lexical meanings are ineliminably mediated by complex mental constructs.[8] This suggests some subtle reinterpretation of the dominant (in GG) view of semantics: a truth-functional semantics (Chierchia 2006; Chierchia and McConnell-Ginet, 1990; J. A. Fodor 1987; J. D. Fodor 1980; Heim and Kratzer 1998; Higginbotham 1985; Pustejovsky 2006; von Fintel and

[6] Simplifying a bit, a Complementizer Phrase (CP, introduced by *that, whether*, and similar) is a proposition, while a rich *v*erb phrase (*v**P), inclusive of auxiliaries, modals, tense, and inflection, is a unit of predication. A Determiner Phrase (such as *the man, many cars, a cat*, etc.) is a unit of specification. Its status as a Phase is still debated.

[7] A case offered by Chomsky is that of the Charles River, outside MIT. What if it dried out completely and cars started using its bed, what if it froze solidly and traffic were allowed to use it? It would still be referred to (at least for some time) as the Charles River. The case he offers for the utter impossibility of a term to have any physical external referent is that of London. We can say, in the same sentence, that London is polluted, mostly Victorian, awfully expensive, and culturally alive. If it were totally destroyed in a catastrophe, it could be totally rebuilt, say, 30 miles from where it is now. No physical object can possibly be, at the same time, a bubble of air (pollution); a set of buildings (Victorian); a flow of highly priced commercial transactions (expensive); a space for concerts, exhibitions and cinemas (culturally alive); and a lot more.

[8] For a radically different (entirely causal-extensional) theory of reference, see Fodor and Pylyshyn (2015).

Matthewson 2008). Truth values (true, false, indeterminate) are themselves to be interpreted as corresponding compositional mental constructs out of more local mental constructs. The work of Paul Pietroski (2005 and Chapter 9, this volume), with the interesting notion of "truth indicators" (originally introduced by Chomsky) comes closer to this desideratum.[9] For a similar internalist approach to meaning, see McGilvray (1998, 1999, 2014).

In order to see how such a view can be understood in our scheme, we need first to introduce the formalism of doubling states and operators in QFT. We will show that such doubling is germane to this conception of semantics, because it closes the system without any appeal to "external" referents.

4.1 The Open System and Its Copy

We observed earlier that time-reversal symmetry is broken moving along the X-bar tree in time. It is such a time irreversibility that offers the possibility of extending to linguistics concepts and formalism typical of open *dissipative structures* (Freeman and Vitiello 2006, 2008; Prigogine 1955; Prigogine and Glandsorff 1971). In the study of a given dissipative system – denote it by A – attention is focused on balancing the reciprocal interaction between the system and its environment – denote it by $\tilde{A}$ – in such a way that the two parts, A and $\tilde{A}$, as a whole constitute a closed system. From such a perspective, the environment $\tilde{A}$ can be considered the "copy," or "double" of the system A.

Since in general the system A is described in terms of its constituents, or degrees of freedom, denote them by A_k and write $A = \{A_k\}$. The doubling process is called in QFT jargon "doubling of the degrees of freedom" and for each A_k one considers its double or tilde-operator $\tilde{A}_k$, thus $\tilde{A} = \{\tilde{A}_k\}$. This general strategy is applied to any generic open system A. In syntactic systems $\{A_k\}$, it can be shown (see PPV) that the $\tilde{A}_k$s correspond to unpronounced copies: mute at the interface between NS and the SM system, but crucially

[9] Two of Pietroski's clear examples of the impossibility of a mind-independent external referent for lexical meanings and sentences are (1) *France is hexagonal and it is a republic* and (2) *The paint is green, as are the apples and the houses*. For (1), it is hard to see which physical object could simultaneously be a large geometric surface and a kind of government. For (2), the alleged extension of "green," in this context, would have to include paint (stuff, as opposed to countable things, but green throughout); some apples (countable things, but green only on the surface); some houses, green in some suitable way. And, of course, the shades of green need not be the same in each case. So, rather than say that sentences have truth conditions, one can say (following suggestions made by Chomsky back in 1977 (Chomsky 1977) that the sentences provide sketches of – or if one prefers, scaffoldings for – complete thoughts, but with room for developing the pictures in various ways. Pietroski has tried to spell this out by treating each lexical item as a device for accessing a (copy of a) concept from a memory address that may be shared by a family of concepts. Principles of composition will constrain which lexical choices lead to coherent thoughts (also Pietroski personal communication, June 2015).

present and appropriately interpreted at the CI interface. The tilde-operators are essential to "fasten" the derivation of the sentence and its meaning.[10]

In other words, what is technically called in physics a dissipative system is an open system interacting with the environment in which it is embedded. To carry out the analysis of system properties, one must consider the fluxes of energy, matter, information, and so on exchanged between the system and its environment. This implies that the study of dissipative systems cannot ignore the study also of properties and features of the environment. This means that instead of considering the system separated from the environment, one doubles the space and the operators, introducing the so-called tilde-operators. One must now deal with a doubled system: the system A and its double or copy Ã. Since the fluxes between A and Ã must be balanced, one may think indeed of Ã as a copy of A, in the sense that Ã represents the sink where outgoing fluxes from the source A go, and vice versa. Symmetrically and reciprocally, A also represents the sink where the outgoing fluxes from source Ã go. Doubling the space and the operators creates a strict correspondence between each operator and its double (the tilde-operator). This two-way interaction is quite specific. In the case of language, each copy interacts with the initial (in a sense, the "original") element and meaning is accordingly extracted at CI. As CI well "understands," the interpretation is determined by this dual correspondence. These copies or tilde modes provide the dynamical reference (the "address") of the non-tilde modes. The result is a logical self-consistency (inclusion of the reference terms) of languages – the basis, we think, of an internalist semantics.

4.2 *Built-in Reference Systems*

We are ready now to consider the reference problem. Let's use an imprecise, but intuitively clear, example: what makes a mathematical or logical theorem true or false is something external to it, a formal procedure of validity checking (see, among many sources, Boolos 1993). Here, on the contrary, with QFT doubling, we have only internal checks. The doubled system $\tilde{A} = \{\tilde{A}_k\}$ is the complement of an internal system of derivations $\{A_k\}$. One can show, for example, that observable properties of the (internal) system (the non-tilde operators A_k) derive from the behavior of the doubled tilde system of

[10] There are well-known parametric differences concerning Phonological Form (PF) between different languages as to which copy is pronounced and which one is deleted (unpronounced) at the SM interface. The most frequent case is that only the higher copy is pronounced, but there are exceptions (all copies can be pronounced or only the lower copy (Boeckx, Hornstein, and Nunes 2007 and chap. 8 of Hornstein, Nunes, and Grohmann 2005). Even in languages where more than one copy is pronounced, this only applies to "short" lexical items (the equivalents of English *who, which, what*), never to whole Noun Phrases (such as *the man, my sister*, and similar). We will not go into further details here.

operators $\tilde{A}_k$, which now, in the QFT doubling formalism, are incorporated into (belong to) the closed system $\{A_k, \tilde{A}_k\}$. This means that tilde modes $\tilde{A}_k$ constitute the dynamic address, the reference for the non-tilde ones A_k (the reverse is also true). For example, the losses in the system $\{A_k\}$ are determined by computing the gains in the system $\{\tilde{A}_k\}$, since the (global) $\{A_k, \tilde{A}_k\}$ system is closed and fluxes between A_k and $\tilde{A}_k$, $A_k \rightleftarrows \tilde{A}_k$, for each k, are balanced in the construction. We note that such a construction implies an entanglement of tilde and non-tilde modes A_k and $\tilde{A}_k$ as a dynamical result such that the behavior, in any computational sense, of one of the modes is bounded and constrained by one of its tilde conjugate modes. In this sense, any computational process is internal to the closed system $\{A_k, \tilde{A}_k\}$.

This also shows the relevance of copies in the Minimalist Program. They play the role of the $\tilde{A}$ elements in our construction. They are crucial in determining (indeed providing the address of) the entire conceptual content of the considered linguistic structure. Indeed, both pronounced (non-tilde) and unpronounced (tilde) copies are interpreted. Tilde modes provide the dynamic reference for the non-tilde ones. Remarkably, they are built in the scheme proposed here; they are not imposed by some constraint external to the linguistic system. It is in this specific sense that we speak of "self-consistency": our formal scheme is computationally (logically) self-contained.

In essence, from 2012 to time of writing, the bold hypothesis is that Merge no longer forms sets that have a category. It works freely and without constraints, rather like Feynman's sum of all histories before amplitudes give the wave function (see the quote at the start of this chapter). Categories are needed only at the interface with CI, for CI needs labeled heads: which one is a verb, which a noun, an adjective, and so on. A minimal search process called the Labeling Algorithm accomplishes this (Chomsky 2013a, 2015, see also the Appendix). Categorization and non-commutativity are necessary only at the CI interface. Order is important at the SM interface (what to pronounce first, second, etc. and what not to pronounce at all – deleted copies), but not the CI. Order is a reflex of the SM system, not feeding NS or CI.

If Merge is unconstrained and does not produce ordered sets, we initially have symmetry (i.e., before the interfaces with CI and SM). Labeling and ordering at the interfaces break this symmetry and create order. This process does not involve material transfer, obviously excluded in the case of language. Thus, when spontaneous symmetry occurs, the system may be situated in different dynamical regimes or physical phases, described by different spaces of the states of the system, each labeled by a specific value assumed by the order parameter. This process of dynamical generation of physically different phases, each characterized by collective, coherent waves, is represented by the ladder operators S – "foliation" in QFT jargon.

We now have a quantitative characterization of the interfaces where NS makes contact with the CI system: at these interfaces we get spontaneous breakdown of symmetry. It is there that a specific meaning, concept, or LF arises from a continuous context of possible concepts by selecting out one representation of the algebra from many that are unitarily inequivalent (each corresponding to a different concept). The concept appears as a collective mode, not a result of an associative process pulling together lexical pieces, words, and so on. Collectiveness arises from "phase coherence," whose carriers are the collective Nambu-Goldstone fields. We thereby understand why ordering becomes relevant only at interfaces. Order is lack of symmetry and appears only when symmetry is spontaneously broken.

We have then a dynamical transition that takes us from a numeration of lexical items to syntax and from syntax to the LF of a sentence, then from LF to meaning. This brings us to identification of the manifold of concepts, to self-similar properties of X-bar trees and their dissipative character (breakdown of the time-reversal symmetry), then to the role of copies in the conceptual interpretative system CI. Copies in the CI system are built into the computationally self-contained algebraic scheme we sketch.

5 Wrap-up

What we suggest here are, basically, instantiations in linguistics of a number of algorithms and concepts developed in Quantum Field Theory. In Chomsky's own words, as we saw, Narrow Syntax may well have "appropriated" these operations as "third factors in language design." If true, this is further evidence that language is indeed part of the natural world and that it is advantageous to approach language as a natural object, treating linguistics as a natural science.

The question then emerges: "Why do humans alone have language?" One reason is that other species either master no recursion at all or a very limited kind of recursion (only up to two in the syntax of songbirds and one in forming heaps of heaps in some primate species). Another is the evident lack of any labeling algorithm and of syntactic categories, in spite of some form of object categorization. Finally, the limited semantics of calls in other species is purely extensional: each signal corresponds rigidly to one external object or event (accessible food, possible mate, predator from the sky, predator from the ground, and similar). The kind of internalist semantics discussed earlier and the mastery of "truth indicators" (in Chomsky's and Pietroski's sense) are unavailable to other species. Yet how this mutation has allowed the human brain to master unlimited recursive Merge, supplement it with the labeling algorithm (see the Appendix), and gain access to an internalist semantics remains, for the moment, unknown.

It is remarkable that the crucial QFT mechanism of foliation of the space of states appears to be isomorphic with the basic dynamics underlying the linguistic phenomena observed at a macroscopic level. It might well be possible, then, that the basic quantum dynamics underlying the richness of the biochemical phenomenology of the relevant brain functions will one day explain in some detail the basic mechanisms of linguistic optimal computations.

Appendix

The Labeling Algorithm (LA)

In essence: Chomsky offered the solution that is most principled and that comes closest to the Strong Minimalist Thesis:

> For a syntactic object SO to be interpreted, some information is necessary about it: what kind of object is it? Labeling is the process of providing that information. Under Phrase Structure Grammar and its offshoots, labeling is part of the process of forming a syntactic object SO. But that is no longer true when the stipulations of these systems are eliminated in the simpler Merge-based conception of UG. We assume, then, that there is a fixed labeling algorithm LA that licenses SOs so that they can be interpreted at the interfaces, operating at the phase level along with other operations. The simplest assumption is that LA is just minimal search, presumably appropriating a third factor principle, as in Agree and other operations. In the best case, the relevant information about SO will be provided by a single designated element within it: a computational atom, to first approximation a lexical item LI, a head. This LI should provide the label found by LA, when the algorithm can apply. (Chomsky 2013a: 43)

The issue of the interfaces is thus summarized: "We assume that a label is required for interpretation at the interfaces, and that labels are assigned by a minimal search algorithm LA applying to [a Syntactic Object] an SO (like other operations, at the phase level) (Chomsky 2013a: 46). The output of the Labeling Algorithm is thus needed at the CI interface for interpretation; it licenses some Syntactic Objects (SOs) so that they can be interpreted at the interfaces. It applies at the Phase level (like other operations, except External Merge that is needed to form the structure). It operates under the constraint of minimal search (a third factor principle). In what Chomsky characterizes as "the best case," lexical items (LIs) may provide the label found by the Labeling Algorithm. If LA finds a Head, then LA selects it. In many languages, specific morphemes unambiguously characterize nouns, verbs, adjectives, and adverbs. These are less prominent in English, with some exceptions. For instance, the suffix *–ion* characterizes nouns (*reunion, transmission*, etc.), the suffix *–ly* characterizes adverbs (*happily, swiftly*, etc.), and the suffix *–ble* characterizes adjectives (*edible, reusable, publishable*, etc.). Let's use the term "features" more generally to single out such elements in the different languages. It is reasonable to assume, therefore, that LA seeks features (not only whole LIs), perhaps *only* features, which are atoms of computation, but not Lexical Items. Such atoms of computation have an internal structure, determine word-internal hierarchies,[11] and can come in bundles. LA seeks feature bundles or atoms of computation. Discontinuous elements are invisible to LA. Lexical roots can be ambiguous (especially in English) and then do not qualify as labels. Then a morphological functional head *f* (say *–ion* for nouns) will become the label, because no other element is visible to LA. The interested reader may find further details on LA in the cited literature (especially Chomsky 2013a, 2015).

References

Alfinito, E., R. G. Viglione, and G. Vitiello 2001. "The Decoherence Criterion." *Modern Physics Letters B* 15:127–135.

Beige, A., P. L. Knight, and G. Vitiello. 2005. "Cooling Many Particles at Once." *New Journal of Physics*. 7(9):96-105.

Blasone, M., P. Jizba, and G. Vitiello. 2011. *Quantum Field Theory and Its Macroscopic Manifestations*. London: Imperial College Press/World Scientific.

Boeckx, C., N. Hornstein, and J. Nunes. 2007. "Overt Copies in Reflexive and Control Structures: A Movement Analysis." In A. Conroy, C. Jing, C. Nakao, and E. Takahashi, eds. *University of Maryland Working Papers in Linguistics* 15:1–46.

Boolos, G. 1993. *The Logic of Provability.* Cambridge University Press.

Chierchia, G. 2006. "Formal Semantics." In E. K. Brown, R. E. Asher, and J. M. Y. Simpson, eds. *Encyclopedia of Language and Linguistics Vol. 1*. Amsterdam: Elsevier. 564–579.

Chierchia, G., and S. McConnell-Ginet. 1990. *Meaning and Grammar: An Introduction to Semantics*. Cambridge, MA: MIT.

Chomsky, N. 1977. *Essays on Form and Interpretation*. New York: North Holland.

1981. *Lectures on Government and Binding (The Pisa Lectures)*. Dordrecht: Foris.

1982. *Some Concepts and Consequences of the Theory of Government and Binding*. Cambridge MA: MIT.

1986. *Knowledge of Language: Its Nature, Origin, and Use*. New York: Praeger Scientific.

1995. *The Minimalist Program*. Cambridge MA: MIT.

2013a. "Problems of Projection." *Lingua 130*:33–49.

[11] For instance, morphemes of negation (such as *in- im- un-*) are the highest (*infrequent, inedible, unpublishable*, etc.) modes (such as *re-* to signal repetition, *ir-re-deemable, ir-re-producible*, etc.) come lower and qualifiers (such as *–ble* to signal potentiality) the lowest (see Di Sciullo 2005; Di Sciullo and Williams 1978).

2013b. "Notes on Denotation and Denoting." In I. Caponigro and C. Cecchetto, eds. *From Grammar to Meaning: The Spontaneous Logicality of Language*. Cambridge: Cambridge University Press. 38–45.

2013c. "What Is Language" (First lecture of Dewey Lectures 2013: "What Kind of Creatures Are We?" *The Journal of Philosophy* 110(12): 645–662.

2015. "Problems of Projection: Extensions." In E. Di Domenico, C. Hamann and S. Matteini, eds. *Structures, Strategies and Beyond. Studies in Honour of Adriana Belletti*. Amsterdam: John Benjamins.

2017. "Puzzles about Phases." In L. Franco and G. Bellucci, eds., *Linguistic Variation: Structure and Interpretation – A Festschrift in Honour of M. Rita Manzini*. Berlin and Boston: Mouton de Gruyter.

Chomsky, N., and J. McGilvray, 2012. *The Science of Language: Interviews with James McGilvray*. Cambridge University Press.

Close, F. 2011. *The Infinity Puzzle: Quantum Field Theory and the Hunt for an Orderly Universe*. New York: Basic Books.

Di Sciullo, A. M. 2005. *Asymmetry in Morphology*. Cambridge, MA: MIT.

Di Sciullo, A. M., and E. Williams, 1978. *Words*. Cambridge, MA: MIT.

Epstein, S., H. Kitahara, and D. Seely. 2012. "Structure Building That Can't Be." In M. Uribe-Etxebarria and V. Valmala, eds. *Ways of Structure Building*. Oxford University Press. 253–270.

Feynman, R. P. and A. R. Hibbs. 1965. *Quantum Mechanics and Path Integrals*. New York: McGraw-Hill Co.

Feynman, R. P., R. B. Leighton, and M. Sands. 1963. *The Feynman Lectures on Physics* (Vol. 1). Reading, MA: Addison Wesley.

Fodor, J. A. 1987. *Psychosemantics*. Cambridge, MA: Bradford Books/MIT.

Fodor, J. D. 1980. *Semantics: Theories of Meaning in Generative Grammar*. Cambridge, MA: Harvard University Press.

Fodor, J. A. and Z. Pylyshyn. 2015. *Minds without Meanings: An Essay on the Content of Concepts*. Cambridge, MA: MIT.

Freeman, W. J., and G. Vitiello. 2006. "Nonlinear Brain Dynamics as Macroscopic Manifestation of Underlying Many-Body Dynamics." *Physics of Life Reviews* 3:93–118.

2008. "Brain Dynamics, Dissipation, and Spontaneous Breakdown of Symmetry." *Journal of Physics A: Mathematical and Theoretical* 41 (30): 30–42.

Gilmore, R. 1994. *Lie Groups, Lie Algebras and Some of Their Applications*. Malabar FL: Krieger.

Haegeman, L. 1991. *Introduction to Government and Binding Theory*. Oxford: Blackwell.

Heim, I. and A. Kratzer. 1998. *Semantics in Generative Grammar*. Oxford: Blackwell.

Higginbotham, J. T. 1985. "On Semantics." *Linguistic Inquiry* 16(4):547–593.

Hornstein, N., J. Nunes, and K. K. Grohmann. 2005. *Understanding Minimalism*. Cambridge University Press.

Idsardi, W. J., and J. Uriagereka. 2009. "Metrical Combinatorics and the Real Half of the Fibonacci Sequence." *Biolinguistics* 3(4):404–406.

Kayne, R. S. 1994. *The Antisymmetry of Syntax*. Cambridge, MA: MIT Press.

McGilvray, J. 1998. "Meanings Are Syntactically Individuated and Found in the Head." *Mind and Language* 13:225–280.

McGilvray, J. 1999/2014. *Chomsky: Language, Mind and Politics*. Cambridge: Polity Press. Second extensively revised edition (2014).
Medeiros, D. P. 2008. "Optimal Growth in Phrase Structure." *Biolinguistics* 2(3):152–195.
2012. *Economy of Command*. Doctoral dissertation, Department of Linguistics, University of Arizona.
Medeiros, D. P., and M. Piattelli-Palmarini 2016. "The Golden Phrase: Steps to the Physics of Language." In A. Gallego and R. Martin, eds. *Language, Syntax, and the Natural Sciences*. Cambridge University Press.
Moro, A. 2000. *Dynamic Antisymmetry*. Cambridge, MA: MIT.
Moro, A. 2013. "Rethinking Symmetry: A Note on Labeling and the EPP." *The Equilibrium of Human Syntax. Symmetries in the Brain*. New York: Routledge. 200–203.
Piattelli-Palmarini, M., and J. Uriagereka. 2008. "Still a Bridge Too Far? Biolinguistic Questions for Grounding Language on Brains." *Physics of Life Reviews* 5(4):207–224.
Piattelli-Palmarini, M., and G. Vitiello. 2015. "Linguistics and Some Aspects of its Underlying Dynamics." *Biolinguistics* 9: 96–115. See also arXiv:1506.08663 at http://arxiv.org/abs/1506.08663
Pietroski, P. M. 2005. "*Meaning Before Truth*." In G. Preyer and G. Peters, eds. *Contextualism in Philosophy*. Oxford University Press. 225–300.
Prigogine, I. 1955. *Thermodynamics of Irreversible Processes*. New York: John Wiley and Sons.
Prigogine, I., and P. Glandsorff. 1971. *Thermodynamic Theory of Structure, Stability and Fluctuations*. New York: John Wiley and Sons.
Pustejovsky, J. 2006. "Lexical Semantics: Overview." In B. Keith, ed. *Encyclopedia of Language and Linguistics*. Oxford: Elsevier. 98–106.
Shah, M. N., H. Umezawa, and G. Vitiello. 1974. "Relation Among Spin Operators and Magnons." *Physical Review B* 10:4724–4736.
Umezawa, H. 1993. *Advanced Field Theory: Micro, Macro and Thermal Concepts*. New York: American Institute of Physics.
Vitiello, G. 1974. "Dynamical Rearrangement of Symmetry," *Dissertation Abstract International 36–02*, Section B:0769
Vitiello, G. 2001. *My Double Unveiled*. Amsterdam: John Benjamins.
von Fintel, K., and L. Matthewson. 2008. "Universals in Semantics." *The Linguistic Review* 25:139–201.
Wybourne, B. G. 1974. *Classical Groups for Physicists*. New York: Wiley.
Zee, A. 2010. *Quantum Field Theory in a Nutshell* (2nd ed.). Princeton NJ: Princeton University Press.