Rethinking the Cartesian Theory of Linguistic Productivity
Forthcoming in *Philosophical Psychology*

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Abstract

Descartes argued that productivity, namely our ability to generate an unlimited number of new thoughts or ideas from previous ones, derives from a single undividable source in the human soul. Cognitive scientists, in contrast, have viewed productivity as a modular phenomenon. According to this latter view, syntactic, semantic, musical or visual productivity emerges each from their own generative engines in the human brain. Recent evidence has, however, led some authors to revitalize the Cartesian theory. According to this view, a single source or a single mechanism in the human brain produces productivity in every cognitive domain, whether in the domain of music, semantics or syntax. In this article, we will address recent evidence concerning the single source hypothesis from brain-imaging studies, linguistics, cognitive theories of music perception, biology of cognition and cognitive development, along with several objections that have been presented against this hypothesis. We formulate two versions of the Cartesian theory which combine the more recent computational theory of cognition with Descartes’ view on productivity.

Keywords
Productivity; merge; recursion; single source hypothesis; modularism; Descartes; biolinguistics; bare phrase structure; computational theory of mind

Acknowledgements
This research project was financially supported by the Academy of Finland (project number 1106071) for both authors and the Finnish Funding Agency for Technology and Innovation (Tekes) for the first author.
When Noam Chomsky (1966) termed the generative approach to human language as Cartesian Linguistics, he was emphasizing several similarities between his own approach to language and that of Descartes. One striking similarity between the two scholars was that they both emphasized the productivity of human language and thought. Productivity refers to the open-endedness of our thought that allows us to generate and manipulate an unbounded number of objects. In the case of linguistic communication, for instance, “the normal use of language is constantly innovative, unbounded, apparently free from control by external stimuli or internal states, coherent and appropriate to situations” (Chomsky, 1988, p. 5).

The authors disagreed with how productivity should ultimately be explained. Descartes asserted that linguistic productivity emerges from an immaterial soul, whereas Chomsky has attempted to describe the phenomenon as part of the natural world. Moreover, Descartes assumed that human productivity originated from a single, undividable soul, whereas at least since the mid-1960s the Chomskian theory of productivity was based on a modular conception of linguistic knowledge. The modular view amounts to the claim that not only is there a separate, domain-specific generative source for linguistic productivity, as compared to musical, mathematical or visual productivity, but that linguistic productivity itself is expressed through several generative linguistic levels such as deep structure, surface structure and later a host of others (Chomsky, 1965). It has been assumed that the same is true of other cognitive domains, such as music, which would be based on its own “grammar of music” constituted of several musical generative levels (Jackendoff & Lerdahl, 2006). The overall picture that emerges from these works is that the human mind is equipped with a plethora of generative engines, all computing with their own representational mediums, or languages of thought in Fodor’s (1975) vernacular.

This has recently begun to change. What some linguists, neuroscientists, and cognitive scientists now speculate resembles the Cartesian model of productivity in the sense that they attribute this capacity to a supramodal mental system which is not entirely domain specific (e.g., Brattico, 2005; Chomsky, 1988, 1995, 2006; Corballis, 1991; Friederici et al., 2006a; Maess et al., 2001; Patel, 2008; Tettamanti & Weniger, 2006; Ullman, 2004). In this paper we will attempt to revitalize the Cartesian theory of productivity in the context of modern cognitive sciences. The paper is organized so that Section 2 discusses some of the background of the Cartesian model of productivity and the theory of formal languages, while Section 3 attempts to present a modernized version of the Cartesian theory. We present two forms of the Cartesian model, the strong form and the weak form, both of
which are based on Turing’s symbolic theory of thought combined with the Cartesian view on productivity. We will discuss two concrete incarnations of this idea, one emerging from linguistics and another from the neurosciences. In Section 4, we deal with several objections to this model. This discussion will lead us to rethink certain aspects of modularity and the current empirical evidence concerning cognitive dissociations.

2. Productivity

Before going into the main topic of this essay, we will shed some light on various technical matters relating to productivity that are indispensable to our research agenda (e.g., finite-state models, context-free grammars, hierarchical representations, constituency relations and recursion). Readers familiar with these notions may, however, want to skip this section.

Beyond any doubt our behavior is productive. For instance, it is possible to assemble complex linguistic phrases from linguistic parts virtually without any limit. Thus, we can say that John loves Mary, but also that John thinks that Mary loves Bob, John believes that Mary thinks he loves Tanya, and so on. Descartes paid due attention to this phenomenon and even argued that such behavior falls outside of the scope of the materialism of his day. According to Descartes, “We can easily understand a machine’s being constituted so that it can utter words, and even emit some responses to action […] which brings about a change in its organs, but it never happens that it arranges its speech in various ways, in order to reply appropriately to everything that may be said in its presence, as even the lowest type of man can do” (Descartes, 1997, p. 107). Descartes reasoned that this open-endedness of our linguistic behavior was something that could not be explained entirely in mechanical terms, as was later emphasized by Chomsky:

Descartes noticed that certain phenomena do not appear to fall within the mechanical philosophy. Specifically, he argued, no artifact could exhibit the normal properties of language use: the fact that it is unbounded in scope, not determined by external stimuli or internal state, not random but coherent and appropriate to situations though not caused by them, evoking thoughts that the hearer might have expressed the same way—a collection of properties that we may call “the creative aspects of language use” (Chomsky, 1993, p. 36).

After pointing out that material processes or any type of “machines” were insufficient to explain human productivity, Descartes relied on the non-material soul in attributing such behavior to humans. We will return to this dualistic theory presently, but it is common knowledge that the theory is beset
with several difficulties. Here we take up one particular problem, the fact that Descartes’ theory of material processes was already too limited. Descartes worked within the context of the mechanical philosophy according to which the material world was regulated by means of what we could describe as ‘contact mechanics’. According to this scheme, physical motion was conceived as “the transference of one part of matter or one body from the vicinity of those bodies that are in immediate contact with it, and which we regard as in response, into the vicinity of others” (Descartes, 1997, p. 321). Like billiard balls on a table, physical elements push and pull each other by virtue of being in direct contact with each other. In part it was this limited conception of the material world that led Descartes to doubt whether it could produce anything resembling the freedom and productivity of human thought and language. To his credit, this reasoning was later shown to be quite correct (see below). What was wrong with Descartes’ argument was the premise that such a simple contact mechanism is all there is in the material world. Three centuries later, Alan Turing showed that material processes can do much more.

Turing approached the same problem as Descartes from a slightly different angle. His main goal was to make the notion of mathematical proof rigorous. Mathematical thinking is a form of human activity that cannot be understood without having a theory of productivity. The simplest mathematical notions, such as the set of natural numbers, require the use of some form of productive capacity, an ability to grasp the open-ended nature of this set. Furthermore, Turing followed Descartes’ reasoning in asking whether productivity could be explained in entirely mechanical terms, and thus without any reliance on obscure mental notions such as intuition, insight or the immaterial soul. It was precisely the reliance on these notions that hampered mathematical reasoning, and so it became impossible for Turing to accept Descartes’ conclusion that the ability would be based on something as obscure as the “immaterial soul.”

Whereas Descartes attempted to capture the mental properties of human thought, Turing begun by modeling the manipulation of symbols with paper, pencil and eraser. It turned out that this kind of concrete bookkeeping could be implemented by a mechanical device and that the resulting notion, the Turing machine in contemporary terminology, was so powerful that it left very little to be explained by other means. It was soon obvious that this notion allows us to capture Descartes’ notion of productive behavior as well, in essence by relying on dynamic memory and recursion.

Dynamic memory refers to a system, such as a paper, tape or some storage capacity in our brain, which can be used to store symbols and symbol structures. In addition to the storage medium, a set of computational processes (reading, writing) are invoked that are able to process the symbols contained in the dynamic memory. We call this part of Turing’s theory the symbol manipulation hypothesis. Another side of this proposal was the idea of a rule system containing recursive definitions
and recursive procedures. A recursive definition or procedure is one which contains itself in its own
definition. For instance, the definition of natural numbers by Peano’s axioms contains two clauses
among the other axioms, one which says that 0 is a number and another which says that if \( n \) is a
number, then \( n + 1 \) (the successor of any number) is also a number. The second clause makes the
definition recursive because it utilizes the concept of number within the definition of the concept of
number itself. In computer programming, recursion is invoked for example when a function calls
itself. The importance of a recursive definition lies in at least three facts. First, the notion is
mathematically well-defined. It can therefore be applied in a completely rigorous way. Second, it
allows us to capture a plethora of mathematical and empirical phenomena involving Cartesian
productivity. For instance, the set of natural numbers can be defined by relying on a recursive axiom.
Third, there is neither a conceptual nor an empirical problem in assuming that the human mind/brain
somehow implements recursive processing. We will return to this matter presently.

Turing’s notion of symbol manipulation together with recursion has proved to be powerful in
the sense that most scholars think today that all mechanical processes can be described with these
simple assumptions. Descartes’ productivity is not an exception; thus, recursion and recursive search
were, and still are, used to describe human thinking more generally (Newell & Simon, 1961, 1963;
Newell, 1990). However, the idea that Turing’s symbolic/recursive model is sufficient to entail
productivity does not yet imply that it is also necessary. Of particular importance in this connection is
Chomsky’s demonstration that human language is based on symbolic/recursive computations. More
specifically, he argued that language exhibits productive behavior that can be captured with nothing
less powerful than context-free phrase-structure grammars (Chomsky, 1957). The details of this
concept are not important, only the fact that these grammars are based on the two components of
Turing’s theory, the symbolic theory of thought and recursion. We illustrate both in Figure 1, which
contains one sentence in English and its analysis in terms of a phrase-structure grammar. This analysis
is a simplistic description of the real linguistic structures underlying the representation of sentences,
but it serves to illustrate the main idea behind the phrase-structure grammar.

--- Figure 1 here ---

Figure 1 legend. The sentence *John believes that the dog chased the cat* as analyzed by a phrase-
structure grammar. The elements of the sentence are organized in a hierarchical manner, with various
types of phrases (NPs, VPs, Ss) dominating the words. The lower sentence (S) contains a similar
structure, which is not explicitly drawn.

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The sentence in Figure 1 consists of a highest node, S, which contains two constituents, NP (the noun phrase John) and VP (the verb phrase believes that ...). According to this scheme, what lies behind natural language sentences are hierarchical representations that are made of whole-part relations. In addition, the VP contains the main verb believes and another sentence as its complement (dog chased the cat). This requires a recursive definition, as the notion of sentence now encompasses the notion itself. Thus, recursion is implemented by assuming that one part, such as a sentence, may contain another object of the same type as its constituent (and so on, ad infinitum). This formalism requires symbolic/recursive mechanisms for its implementation. Although the details are moot, this type of explanation is harnessed routinely in contemporary linguistics. Correspondingly, Chomsky managed to argue persuasively that the symbolic/recursive processes are not only sufficient to explain Cartesian productivity but also necessary, and hence that the human mind has computational mechanisms capable of processing hierarchical symbol structures together with recursive embedding.

This is almost everything we need to understand about the contemporary linguistic theory of productivity in order to follow the arguments in this article. Let us return to Descartes. Descartes did not have Turing’s and 20th century mathematicians’ insights available, and thus he resorted to the immaterial soul in attributing productive behavior to humans. But there was one aspect of this dualistic explanation that might capture the attention of a contemporary scholar working with similar topics. Namely, Descartes’ immaterial soul, his explanation of human productivity, was “indivisible” (1997, p. 131). By this notion he referred to the fact that “when I consider the mind, that is to say, myself inasmuch as I am only a thinking thing, I cannot distinguish in myself any parts, but apprehend myself to be clearly one and entire” (p. 187). For Descartes the “infinitude of ideas of certain things” (p. 170) that belonged to various cognitive domains was not conceived as separate parts from the one whole. Instead, generative behavior originated from the self-apprehended thinking unit that cannot be analyzed into its parts. Seen in this way, productivity has a single source in the human mind.

Why this could be interesting is because if we look beyond linguistic behavior, we can quickly observe that the same type of open-ended behavior emerges in other cognitive domains as well. Take music, another cognitive domain that we are going to discuss later in some detail. Just as in language, musical compositions are literally assembled from some sort of constituents such as pitches, intervals and rhythm, the only limiting factor being our imagination and musical appetite (Patel, 2008). Rather than listing all the cognitive domains which seem to involve productivity, one is led to wonder if there are any cognitive domains which are not productive in the same way. As a first approximation, then, the idea that there is a single source – a single factor – in the human brain that explains productivity irrespective of the cognitive domain seems likely.
Yet, this idea was rejected when Cartesian ideas about productivity were brought to bear on emerging cognitive science in the early 60s. This was because there is compelling evidence in favor of the modular conception of the mind. According to this conception, each cognitive domain is based on its own generative system regulated by domain-specific principles. This is easily illustrated with the grammatical representation of an English sentence, as shown in Figure 1. The structural representation of the sentence is generated by rules which compose a sentence out of a noun phrase and a verb phrase. The important thing to notice about this way of modeling grammar is that noun phrases and verb phrases (etc.) are notions that belong only to language and not, say, to music, mathematics or visual imagery. Similarly, the theory of the semantic interpretation of sentences would be based on a semantic level of representations, which is built from semantic elements of some kind, perhaps something like ‘concepts’. It is this difference between Descartes and present-day cognitive scientists that constitutes the matter addressed in this article. As we will argue below, this gap has recently begun to narrow.

Before we go into the main business of this article, there is one additional concept that needs to be clarified. If the context-free grammar (e.g., Figure 1) is one of the weakest possible models able to capture linguistic productivity, the strongest system which captures what Descartes referred to as mechanistic processes could be identified with finite-state models. These models do not define or process hierarchical structures; instead, they are defined as a cascade of atomistic internal states regulated by inputs and outputs. An example of a finite-state model is illustrated in Figure 2.

Figure 2 legend. The sentence John believes that the dog chased the cat as modeled by a simple finite-state system. According to this scheme, the sentence is represented as a linear sequence of words, whose transitional probabilities are captured by the model. This simplistic scheme can be enhanced with branching nodes, feedback loops, and a learning algorithm. What is crucial is the absence of hierarchical elements such as S, NP and VP. These elements could be projected into the system, but they do not play any causal role in the model.

Finite-state languages encode local transitions or transitional probabilities between two adjacent or proximate elements, with no ability to process hierarchical relations (see Minsky, 1967). Nevertheless, a finite-state system is quasi-productive in the sense that it is capable of iteration, the countless repetition of the same pattern. The relevance of this notion is that finite-state models and symbolic/recursive models constitute two fundamentally different ways to understand the workings of
the human brain. To see what is at stake, consider the phenomenon of linguistic productivity. As
pointed out by Descartes, we can assemble new sentences from previously assembled parts (such as
words) essentially without limit. One problem Chomsky worked on was whether finite-state models
(Figure 2) were sufficient to describe this type of behavior or whether the more powerful
symbolic/recursive models developed by Turing and others were needed. The empirical question thus
boils down to whether linguistic productivity is iterative or involves more complex relations.
Chomsky showed that language is not iterative, for much of the same reason as why the simplest
logical systems, such as propositional calculus, are not iterative: they involve embedded relationships
between elements. We will assume that this view is basically right. What is important to realize here is
that despite the assumption that our linguistic behavior would be based on symbolic/recursive
computations, it does not follow that there are no mechanisms which harness less complex
computational operations, such as finite-state computations.

To illustrate this point, consider another form of linguistic behavior, word formation. Word
formation refers to the ability of the speakers of a language to compose new words from their
sublexical parts. As an illustration, the English word *redden* is composed syntactically and
semantically from two parts, *red* and the causative suffix *-en*. There are several layers of rules which
cover such concatenation. But as of now there is no agreement on how complex rules are needed to
explain this no doubt productive type of behavior. Prima facie, morphological concatenation appears
to be a much simpler operation than the composition of linguistic phrases. It is therefore possible that
this aspect of linguistic behavior is based on a finite-state process that regulates the transitional
probabilities between adjacent elements (e.g., Koskenniemi, 1983). This point becomes important
later on as we began to argue that the fully productive symbolic/recursive processes in the human
brain are not domain-specific; what we then imply as a corollary is that there could still be domain-
specific processes as long as they are not fully productive.

To summarize, Descartes, Turing and Chomsky were interested in explaining human
productivity, our ability to form an endless amount of sentences, numbers, proofs, thoughts, pictures,
ideas, musical compositions and such. While Descartes relies on the immaterial human soul, Turing
was able to design a mechanical model that suffices to produce such behavior. Chomsky showed that
Turing’s symbolic/recursive model (at least the context-free grammar) is also necessary in order to the
explain productivity in the case of human languages. Whereas Chomsky and most cognitive scientists
held a modular view on human productivity, Descartes’ view was that all such behavior emerges from
a single source. What we want to do in this article is to try to combine the Chomsky-Turing model of
human thought with Descartes’ idea that it derives from a single source.
3. Modernization of the Cartesian Hypothesis

3.1. Defining the two Single Source Hypotheses

Descartes’ idea that there is a single underlying factor which explains why we are able to create productive behavior in any cognitive domain should be assumed as the null hypothesis. Suppose that researchers look at a large family containing members from four generations and that several members of this family have some particular disease. There are at least two possible explanations for this situation. One is that each of these members contracted the disease independently of each other, and the accumulation of this property to one family is due to pure chance. The alternative is that there is a single underlying factor which explains why the disease runs in the family. If enough family members show the same symptoms, the rational thing to do would be to reject pure chance and test the second hypothesis. The same goes with productivity. In the case of productivity, virtually all humans have this “disease” in connection with virtually any cognitive domain. The prospects of explaining this scenario by relying on multiple causes and pure chance are vanishingly small, and so we might initially believe that there is a single factor involved.

We present such a Cartesian framework and label it as the single source hypothesis. In essence, our version of the single source hypothesis is the Cartesian model of productivity combined with Turing’s theory of mental processes. We proceed so that we first define the single source hypothesis itself and then in the next sections we illustrate this idea with concrete proposals from recent cognitive science literature and finally, in the last fourth, we discuss numerous objections that have been presented against this model.

We present two versions of the hypothesis, a strong version and a weak version. These hypotheses are defined as follows:

**Strong Single Source Hypothesis:** There is a single symbolic and recursive mechanism that is both necessary and sufficient to create human productivity in the case of any cognitive domain.

**Weak Single Source Hypothesis:** There is a single symbolic and recursive mechanism that is necessary to create human productivity in the case of any cognitive domain.

It is important to note that we intend “human productivity” to refer to the open-ended nature of human behavior. Specifically, the term does not refer to behavior as such since the explanation of human
behavior requires the postulation of a wide variety of mechanisms besides symbolic and recursive mechanisms (e.g., muscle functioning, sensory coordination, and other physiological apparatus). What we mean is that to get generative behavior out of the pre-existing non-generative behavioral repertoire of an organism, a single symbolic and recursive mechanism is both necessary and sufficient (strong version) or necessary (weak version). We could think of this system as simply added on top of existing non-generative systems, for instance, by means of a “genetic event that rewired the brain” in a “single individual, who was instantly endowed with intellectual capacities far superior to those of others, transmitted to offspring and coming to predominate” (Chomsky, 2005a, p. 3 and 12, respectively).

Another important aspect of the definitions is that the “single symbolic and recursive mechanism” is meant to cover any computational mechanism which is posited in order to explain the open-endedness in human behavior. As we will discuss later, we are not concerned about the nature of these explanations—for instance, whether these explanations refer to neuronal processes or use abstract cognitive nomenclature—it is only the fact that they are able to explain productive behavior that matters for present concerns. Some examples of such explanatory notions are reviewed below, but one example, the phrase-structure grammar of natural language(s), was already illustrated in Figure 1.

The ‘necessity part’ of this definition says that there is no other way to achieve generative behavior except by applying the single mechanism. The ‘sufficient part’ says that no additional components are needed. These notions come with two important caveats. First, the whole strong/weak single source hypothesis has the modal force of a psychological law: its truth is determined by the empirical facts of the world. One mechanism M is necessary for the production of some behavior B here in the sense that in the constitution of the normal human mind, one cannot attain B without M. We do not mean to say that a single mechanism would be logically, metaphysically, physically or even biologically necessary to produce such open-ended behavior; what we mean is that this is how the human mind works. Second, a single recursive mechanism can be sufficient to produce productivity in the domain of music, for instance, only if there is some way to connect the symbolic and recursive mechanism with the domain-specific elements within the musical domain. To follow recent ideas from theoretical linguistics, we will call such connections the interface mechanisms. To keep things simple, we assume that these interfaces are part of the recursive mechanism itself.2

Both definitions emphasize symbolic and recursive mechanisms. These terms should be understood as two components of the Turing’s model of mathematical reasoning. There are two reasons why we define the weak/strong single source hypothesis so that it relies on symbolic and recursive mechanisms. The first reason is that there are in our view strong empirical reasons suggesting that in order to capture a particular type of generative behaviour, these notions (or
something formally equivalent) are needed (section 2). The second and more important reason concerns the fact that the several sources we will discuss in the next section in support of the single source hypothesis make the same assumption. In particular, the type of empirical predictions we think that the single source hypothesis ought to make depend on making a distinction between symbolic/recursive computations and finite-state computations.

None of this is to deny the fact that the matter is empirical. It may turn out that the single source hypothesis is not only false but irrelevant due to the fact that the human brain implements nothing like symbolic or recursive computations in Turing’s sense. What may loosely be called “connectionism” in fact sometimes adheres to this point of view. Following this line of thought, we could jettison the assumption of symbolic and recursive computation and then obtain the following more general definition of the same thesis:

*General Single Source Hypothesis: There is one computational mechanism that is necessary (and sufficient) to produce human productivity in the case of any cognitive domain.*

This thesis says that productivity is implemented in a domain-general way, whatever the mechanism that achieves this. If we then substitute “computational mechanisms” with something like “self-organization,” “association” or “propagation of activation in a network,” we obtain what looks like the default assumption in the connectionist psychology. In this case the challenge lies in relating these notions to human productivity, a matter that has already been discussed extensively in print (Chomsky, 1957; Fodor & Pylyshyn, 1988). We will put this debate aside here and assume, following Turing and Chomsky, that a particular type of human reasoning and linguistic behavior requires symbolic/recursive processes. On the other hand, we do not regard this position as a stance against connectionist psychology. Instead, we adhere to a particular hypothesis we call Cartesian modularism, which views modular cognition in the spirit of connectionist psychology.

We will next illustrate these definitions with two examples, one emerging from linguistics and another from the neurosciences. These examples will shed further light on our decision to capture our definitions in terms of symbolic/recursive processes.

3.2 Biolinguistics and the Explanation of Recursion

As pointed out earlier, the early years of cognitive science were dominated by linguistic modularism. It was taken for granted that various generative linguistic domains, such as syntax, semantics and word formation, are regulated by domain-specific generative rules (Chomsky, 1965). One important
step towards the single source hypothesis in linguistics was the introduction of the X-bar theory in the 70s, which led to an abstraction in the content of linguistic rules. According to this view, many crucial grammatical relations were seen to be independent of their categorical (i.e., noun, verb, adjective, etc.) status, so that noun phrases, verb phrases, adjective phrases and other types of grammatical phrases were based on the same abstract category-neutral X-bar scheme, and relational notions, such as specifiers and complements, were derived directly from this scheme (Chomsky, 1970). Some explanatory burden that was previously in the generative phrase-structure rules was now put into the lexicon, which remained a non-generative domain.\(^3\)

In the 90s a further step was taken when the abstract X-bar scheme evolved into what is called the bare phrase structure, an even more austere formalism for representing grammatical relations (Chomsky, 1995, pp. 243-248). The bare phrase structure is assumed to be built by the operation Merge, which takes two symbolic elements X and Y as its input and produces a complex representation \{X, Y\} as its output (Chomsky, 2005b; Collins, 2002). To illustrate this model, if we drop off the language specific information from the representation in Figure 1, what is left is approximately what is presented in Figure 3.

In Figure 3, each node with two branching subnodes represents one instance of Merge. There are no rules such as ‘S → NP VP’ which would require the sentence to be composed out of domain-specific elements such as a noun phrase and verb phrase; rather, virtually the only specifically linguistic material here is constituted by the words, which are in turn considered a non-generative domain, essentially a list of feature bundles. Thus, “syntactic objects are rearrangements of properties of the lexical items of which they are ultimately constituted” (Chomsky, 1995, p. 226). The generative part of the theory has become virtually devoid of any domain-specific assumptions.\(^4\)

If the generative part is devoid of domain-specific assumptions, then we are in effect assuming that the generative part is not domain specific. To how many cognitive domains can this combinatorial operation be applied? In principle, there seems to be no limit, provided that the appropriate interface mechanisms are in place (see note 2). This architecture of language makes it easy to imagine a recursive symbol processor which can create productive behavior in several cognitive domains depending on which type of symbols it applies to and which type of interfaces it is
required to handle. For instance, when Merge is applied to concepts instead of linguistic objects, the result could lead to an “explosive growth of the capacities of thought” allowing the individual with this capacity to “to think, plan, interpret, and so on in new ways” (Chomsky, 2006, p. 10), leading to the “the liberty of the imagination to transpose and change its ideas,” a process which could generate “winged horses, fiery dragons, and monstrous giants” and other imaginary objects, as put by Hume.5 When general recursion is applied to numbers, or abstracted from all particular content, we get the infinite set of natural numbers (Chomsky, 1988, pp. 168-169; 2005b, pp. 5-6). When it is applied to visual perception, we obtain a complex visual pattern composed out of parts (Bickerton, 1995). Thus, we have a linguistic version of the single source hypothesis where the “single symbolic and recursive mechanism” in our definition is identical with Merge as sketched above.

Hauser, Chomsky and Fitch (2002) argue further that the capacity for recursion (i.e., the iterative application of Merge) could be the only uniquely human component of the language faculty. The hypothesis that the \textit{H. sapiens} is the only species capable of productivity among terrestrial creatures and that this is indeed one of the fundamental if not the most important cognitive abilities which distinguish us from other species goes again back at least to Descartes. The hypothesis is widely maintained today (Corballis, 1991, 1992; Herman, Richards & Woltz, 1984; Premack, 1983, 1985; Snowdon, 1982; Fitch & Hauser, 2004; see Gentner et al., 2006 for contrary evidence). The single source hypothesis and such a uniqueness hypothesis are closely related. If humans are the only terrestrial species to have mastered productivity and if they have mastered this skill in \textit{any} cognitive domain, the null hypothesis again in explaining this outcome is the assumption that this capacity must derive from a single source. The reasoning underlying this argument is that if all generative domains had developed and functioned independently, the most likely outcome of this situation would be that the various generative abilities would have been scattered among the existing terrestrial species. In this scenario, while humans could speak generative languages, tamarins would understand natural numbers, chimpanzees would compose musical art (and so forth), but none of the species would be able to understand each other’s generative enterprises. The guiding intuition is that since all productive skills have clustered into one species, they must have a common explanation within that species’ neuronal systems.

Relying on such a uniqueness hypothesis, Corballis (1991) proposed that the human brain possesses a Generative Assembling Device (GAD), a generative system which is “responsible for constructing representations in generative fashion from a small vocabulary of primitive units” (pp. 219). His proposal comes close to the single source hypothesis in that Corballis’ specifically left-hemispheric GAD not only underlies language, but also other cognitive domains such as perception,
mental imagery and the manufacturing of tools. This Generative Assembling Device provides another recent (and to our current knowledge the first) formulation of the “single source” in our hypothesis.

3.3 Neurosciences and the Single Source Hypothesis

If human productivity originates from a single source, we expect to find something in the human brain that is systematically involved in productive processing more generally. Recent brain-imaging data has supported the conclusion that the neuronal resources recruited for symbolic/recursive processing overlap.

Angela Friederici and her co-workers adopted the above framework by Hauser et al. (2002) that only the human brain possesses a generative engine and used brain-imaging methods to find out if this capacity localizes into a specific brain region (Friederici et al., 2006a). By using functional MRI methodology, they contrasted the processing of two types of strings of syllables, one where the strings were built using a finite-state grammar (FSG, Figure 2) and another where the strings followed the hierarchical rules of phrase-structure grammar (PSG, Figure 1). Several brain-regions were activated, of which the results concerning the inferior frontal cortex were the most interesting. First, both FSG and PSG strings activated the frontal operculum (FOP), a region adjacent and posterior to the Broca’s area (BA 44, 45). However, only the PSG strings activated the Broca’s area. The authors then point out that there is evidence from brain imaging and other studies that Broca’s area is involved in the processing of hierarchical structures in the case of other cognitive domains besides language, such as music (Maess et al., 2001; Patel, 2003, 2008). The authors conclude that “different brain regions may serve specific type of computations [i.e., FSG vs. PSG] independent of the particular domain … but they appear to receive their domain specificity, however, as part of a specialized functional network” (p. 2461). Thus, when BA44/45 is involved with a neuronal network involving certain regions in the superior temporal gyrus, its function is to “support the hierarchical reconstruction of the syntactic structure from the sequential input,” but when other regions are involved, the same B44/45 serves hierarchical processing in a “non-linguistic function” (Friederici et al., 2006a, p. 474). According to this hypothesis, the computation of hierarchical representations is supported by Broca’s area at least to some extent irrespective of the cognitive domain, while the domain-specific aspects are provided by various interface mechanisms which connect these regions with other parts of the brain (for similar hypotheses concerning the role of Broca’s area vis-à-vis the processing of hierarchical representations in various cognitive domains, see Brown et al., 2006; Semenza at al., 2006; Tettamanti & Weniger, 2006; Ullman, 2004). We return to this matter in the next section.
The linguistic and neuroscientific arguments converge in an interesting way with the single source hypothesis concerning the origins of productivity. They both seem to suggest that the computation of hierarchical structures could be implemented by a supramodal process that applies to multiple cognitive domains. In the case of brain imaging, the evidence is based on the well-documented fact that the brain regions associated with hierarchical processing in several cognitive domains overlap; in the case of linguistics, the evidence is based on the assumption that the recursive rules underlying language competence, e.g., Merge, are so abstract that they do not seem to be restricted to the linguistic domain.

One issue relating to the single source hypothesis and its interpretation in terms of the neural organization of the human brain concerns the role of neural plasticity. Given the behavioural and neurobiological data we currently have concerning the processing of hierarchical representations, it is entirely possible that although there is a single neuronal feature or set of features which implement productivity in the human mind/brain, the neuronal circuits possessing this feature (these features) could specialize in the course of normal development. According to this explanation, the ‘single source’ for productivity in our definition above would refer to the initial capacity possessed by the relevant neuronal network(s), while diversification is explained by developmental factors and plasticity (Ullman, 2004). This hypothesis appears to be plausible in the light of what we know about the plasticity of the maturing brain (see Demonet et al., 2005). Although we do not want to take a definite stance on the matter, the single source hypothesis as formulated in this article is meant to include this interpretation as well. The single source in the definition refers to some property in the human mind/brain that is both necessary and sufficient to entail the generative capacity, but this property does not have to be instantiated within some specific region of the brain or even by means of the same neural circuits. Instead, it may be a more holistic organizational property of the relevant neuronal networks.

This clarification brings us to a further matter. Suppose that the symbolic and recursive mechanism is produced by some holistic organizational property of the neural networks of the human brain and that different neuronal networks having this property specialize in the course of cognitive development. This scenario is in agreement with the strong single source hypothesis only if this specialization process does not affect the nature of the emerging symbolic and recursive rules themselves, since if it does, each domain could end up having a generative system with domain-specific rules in addition to the domain-specific symbols and domain-specific knowledge. In this scenario, each domain would inhere some aspects of the general single source, but the single source would not be sufficient to produce productivity in the diverse cognitive domains, although it would still be necessary. This, then, gives us the weak form of the single source hypothesis. Since this
scenario is entirely plausible, we think that these two forms of the hypothesis should be carefully
distinguished when addressing the pros and cons of the single source hypothesis. Further, as we will
argue in the next section, many objections that have been leveled against the single source hypothesis
apply to the strong version but not to the weak version. Finally, the weak version is still able to
explain why the generative abilities in various cognitive domains converge in a single species:
humans are the only species that possess the symbolic and recursive mechanism, and its neural
implementation, necessary for full productivity.

4. Objections

In this section, we discuss certain objections to the strong/weak single source hypothesis. The
empirical objections are based on two interrelated issues: modularism and the existence of cognitive
dissociations. Before discussing the empirical objections, we want to clarify one conceptual point.

4.1. Is the single source hypothesis trivial?

According to one objection, attributed to an anonymous referee, “there is an almost trivial single
source hypothesis according to which the hypothesis is framed at the level of concrete mathematics
(or computation theory) and holds that (e.g.) recursion is responsible for (necessary and sufficient for)
productivity across the board, modulo the existence of other systems. Any logical/computational
system needs at least one rule of inference, to get its axioms to work. And so long as one is willing to
sacrifice complexity elsewhere, it is more or less trivial that one rule will do the job across the board.”

Although this assertion is true, this objection invokes a version of the single source hypothesis
that is not the one we want to defend in this paper. We are not interested in the conceptual or logical
possibility of organizing a recursive set (whether consisting of linguistic expressions or natural
numbers) by using one recursive axiom. Rather, as we pointed out in Section 3, the single source
hypothesis has the modal force of a psychological law: its truth is supposed to be determined by the
empirical facts of the world and more specifically, by facts constituting the human mind (under
normal conditions).

To consider the linguistic example more carefully, here is how Chomsky frames the
discussion of the properties of Merge. He first notes that in addition of merging two constituents A
and B into a set \{A, B\}, Merge must also attach a “label,” a specific formal object, to the resulting
complex constituent (Chomsky, 1995, p. 243). The details are not important for the present concerns;
suffice it to point out that this assumption is motivated empirically. But whether Merge actually has
this property is “not a logical necessity; Martian could be different. Rather, it is an assumption about how human language works […]. The proper question in this case is whether the assumption […] is empirically correct, not whether it is logically necessary; of course it is not” (p. 243-244). The single source hypothesis defended in this paper should be understood similarly.

On the other hand, our definition of the single source hypothesis is not explicit about the level of explanation to which we intend it to apply. Is it a hypothesis concerning the actual neural mechanisms of the brain, or is it the more abstract computational rules which these neural systems implement? Indeed, we do not want to make any definite statement about this matter. The single recursive mechanism in our definition is meant to cover any computational mechanism which is postulated in order to explain the open-endedness in human behavior. Whether such an explanation is couched at the level of actual brain mechanisms, or at some computational higher level (or both) is immaterial for the present purposes. For one, the matter is empirical and controversial. But our main reason for remaining ignorant about the levels of explanation is that those pursuing computational explanations of, e.g., our linguistic capacity have done much the same. Chomsky (1995), for instance, argues that there is a particular “problem for the biological sciences that is already far from trivial: how can a system such as human language arise in the mind/brain, or for that matter, in the organic world, in which one seems not to find anything like the basic properties of human language” (pp. 1-2). The question of how the human brain could implement human language is “primarily a problem for biology and the brain sciences, which, as currently understood, do not provide any basis for what appear to be fairly well established conclusions about language” (p. 2). There being no general agreement on how the neuronal systems in the human brain implement recursive computation, we abstain from committing the weak/strong single source hypothesis to any such view. It may be a neurobiological theory, an abstract connectionist scheme capable of rich productive behavior or a symbolic, computational model; what matters for us is simply the question of whether the model uses domain-general or domain-specific recursion.

Let us return to the issue with “labels” in connection with Merge. This is a relatively technical matter within theoretical linguistics, but it brings home one important point. The point is that the bare phrase structure and the associated operation of Merge do not work unless at least some of what look like language specific assumptions are built into its operation. For instance, in addition to copying formal features such as “labels” from constituents A and B to the resulting complex element \{A, B\}, Merge is assumed to be a binary operation, it is allowed to probe A from within the B, and so forth. By saying that Merge does not “work” without such assumptions we mean that without them it does not allow us to derive the properties of human language(s), the fragment of human behavior that this device is designed to capture. Thus, the bottom line for why the properties of Merge are a matter of
psychological laws, and not logical ones, is because a large chunk of the properties of human languages are a matter of human psychology (the rest being based on cultural facts). In fact, as we will show presently, one of the most interesting objections to the single source hypothesis stems from the very same issue: as it can be argued that in order to explain the properties of human languages we need to assume language specific rules and principles, the prospects of constructing a credible psychological theory out of the single source hypothesis threatens to stay out of our reach.

4.2. Cognitive dissociations and the weak single source hypothesis

The most striking and perhaps also the most frequent objection against the strong/weak single source hypothesis (see e.g. Bloom, 1994, pp. 179-181) stems from the fact that there are cognitive dissociations showing that various cognitive domains are processed separately from each other (Gazzaniga, 1999; Peretz & Coltheart, 2003). For instance, social cognition seems, in part, to be a mental ability distinct from language, logic, mathematics, music or face recognition, let alone a host of other cognitive domains.

The weak form of the single source hypothesis is entirely immune to this objection. According to the weak version, every cognitive domain does have its own generative engine which may be dissociated. Each of these engines only inheres some of its essential generative powers from the single source. To put this idea more concretely, suppose that there are specific neuronal networks in the human brain which implement something akin to domain-general Merge. It does not matter to the example at hand where these networks are located, but let us imagine that they occupy areas in the prefrontal cortex and that they become functional within those loci around two years of age when children start to assemble linguistic utterances productively. We can then imagine that as the child grows older, a slow specialization event occurs in which some parts of the frontal areas specialize in processing hierarchical representations in the case of language, while other parts specialize in the processing of hierarchical representations in music. Thus, what was originally a domain-general process turns into an automatized but specialized recursive processing, each processing different cognitive domains within different neuroanatomical locations, each having the potential for its own idiosyncratic properties.

This scenario is compatible with the weak single source hypothesis as long as the single domain-general source (Merge and its neuronal implementation in this example) is still necessary for such a specialization event to occur. We mention this possibility here since, although it is neither a particularly strong nor a particularly interesting hypothesis, it is still capable of explaining the
intuition that since all generative abilities have accumulated in one terrestrial species, there must be a single factor underlying this capacity irrespective of the cognitive domain.

4.3. Cognitive dissociations and the strong single source hypothesis

In the light of the dissociation data the strong single source hypothesis is much more interesting. How can we square this version of the thesis with the fact that the human mind looks so thoroughly modular?

But here we have to keep in mind that it is an entirely different thing to say that the mind is modular than it is to attribute full productivity to each of its modules. First off, it seems too generous to postulate a separate generative engine for each and every cognitive dissociation ever found: there are simply too many of these in our current knowledge to make such claim plausible. One alternative, outlined by Descartes and still in agreement with the evidence on cognitive dissociations, as far as we know, is to regard the mind’s modular parts in terms of non-generative models, thus not attributing them with full productivity. We will call this hypothesis Cartesian modularism on the basis that we abstain from attributing productivity to domain-specific modules. This corollary of the single source hypothesis comes to the following:

**Cartesian modularism. There are no symbolic/recursive computational processes which are domain-specific.**

The important point to note is that this still leaves three types of computational processes and representations that *may* be domain-specific: (1) finite lists (such as the lexicon), (2) finite-state processes (such as associations) and (3) hierarchical processes without recursion. The third mechanism is attained if, for example, we drop off all recursive definitions from the first order predicate calculus and obtain a simple system for expressing propositions with a predicate/relation and a finite number of arguments. Although formally rather trivial, this type of simple logico-linguistic system might well be employed by human (and animal) cognition.

Are there reasons to reject Cartesian modularism? At first, it indeed seems so. Linguists, for instance, argued and still argue that the recursive linguistic rules which were used for constructing hierarchical linguistic representations were specific to linguistic processing. No convincing case was found for the attribution of linguistic rules, such as (1a—b), to the domain of vision, mathematics or music (Lerdahl & Jackendoff, 1983).
Furthermore, early generative theory was much occupied with the idea that even within one cognitive domain, several generative levels may exist. In early Chomskian theory, for instance, linguistic transformations applied to deep structure representations and produced surface structures, both of which consisted of fully generative linguistic levels (Chomsky, 1965, 1981). Any of these assumptions would depart from the single source hypothesis, and they are a commonplace in contemporary linguistics, to say the least.

Cartesian modularism nevertheless leaves room for the possibility that there are language-specific processes as far as these properties are not fully generative. This is the consequence of adopting strong lexicalism with the bare phrase structure theory of syntax. For instance, it is possible that the specifically linguistic properties of Merge(X, Y) emerge from the non-generative constituents X and Y (that is, if X and Y are primitives and not themselves complex; otherwise the complex elements are further dissolved into their parts until the non-generative elements are found). If this is the case, then the need for specifically linguistic productivity becomes much less compelling (see Collins, 2002).

One argument against the single source hypothesis may be drawn from the cognitive theory of music. Jackendoff and Lerdahl (2006), henceforth JL, argue that music has its own musical grammar which underlies our ability to understand music and which performs this task by associating a “string of auditory events with musical structure” (p. 2). Musical competence begins with what they call the “music surface,” an “array of simultaneous and sequential sounds with pitch, timbre, intensity, and duration” which is “basically a sequence of notes” (p. 5). The fact that JL are comparing language with music suggests that the music surface consists of a linear sequence of notes and chords, and is thus comparable to a linear sequence of words in the case of language. This phenomenon therefore falls within the finite-state models (Figure 2). Furthermore, JL explicitly contrast the music surface with hierarchical structures in music. Hierarchical structures fall within the symbolic/recursive models of cognition, expressed by means of phrase-structure grammar and the like (Figure 1). They also suggest that several hierarchical structures are involved in the grammar of music, all with their “own characteristic units and combinatorial principles.” They summarize these findings by noting that “the result of this analysis is a hierarchical, recursive structure in which each note of the melody is related to more stable notes in the structure” so that “the related notes need not be adjacent at the musical surface, but they must be adjacent at some level of abstraction” (p. 23). After noting that the musical piece is based on such a hierarchical structure, they conclude that “the encapsulated music module,
constructing the structure of the music in real time, unconsciously computed its moment-to-moment tensions and attractions regardless of the listener’s conscious memory” (p. 25). Furthermore, they remark that such a process “seems to be specific to music” while “there is no structure like it in linguistic syntax” (p. 27). It is precisely this sort of hypothesis that is at odds with the single source hypothesis, which would limit the domain-specific music module to the capacity for “music surface,” in their terms.

Is their conclusion warranted? Specifically, is there an empirical or theoretical reason which justifies, without reasonable doubt, the postulation of a modularized generative grammar of music? We would treat any such claim with some skepticism, as even the more basic claim that there is an abstract system of musical syntax, on top of the lower level laws of psychoacoustics, is currently controversial (Patel, 2008, p. 260). If the existence of abstract syntax is controversial, it must be the case that the basis for assuming a modularized and fully generative syntax is even more so.

Consider a typical experiment addressing the processing of musical syntax. Tillman et al. (2006) presented subjects with chord sequences which contained a prior context consisting of six chords and a pair of target chords that were identical in both conditions. The prior context was manipulated so that the two target chords, although identical in their absolute sensory properties, were different in terms of their hierarchical position in the system of Western tonal music (one chord sequence being more salient than the other in the musical hierarchy). The participants performed a detection task while listening to the chord sequences. The authors used both response times and brain imaging methods to find out if the participants were sensitive to such subtle differences in the salience of the chord sequences, and the results showed that less salient chord sequences were both slower to detect and that they involved activation in multiple brain areas, including the inferior frontal cortex, when compared with more salient chord sequences.

This data provides one of the most convincing cases for the existence of musical syntax over and above the laws of psychoacoustics. Yet it does not come near to showing that there is a (1) fully generative and (2) modularized system for processing (3) music-specific representations. With respect of part (1), although there is evidence that the musical context matters in the perception of individual musical elements (e.g., Tillman et al.), there is no data which demonstrates that this recognition goes beyond the capacities of Cartesian modularism, i.e., simple memorized lists, associations or reactions, finite-state processes, or non-generative symbolic processes. While it is certain that by using advanced analytical skills one can detect violations of hierarchical rules of music, perhaps both online and offline, the hierarchical “long-distance dependencies posited by music theory cannot simply be assumed to be perceived” (Patel, 2003, p. 675; Patel, 2008, pp. 263-264.). In a recent and
comprehensive discussion on musical syntax, Patel (2008) argued that musical syntax does not obey even the hierarchical constituency structure typical of human language.

On the other hand, composers and to various degrees also listeners are capable of understanding the hierarchical, recursive structure behind music. This assertion does not stand against Cartesian modularism because it is compatible with a model where the recursive hierarchy is based on a generative component, such as Merge, that is not specific to music. Recall that the matter at hand concerns the claim that musical syntax is both fully generative (1) and modularized (2) and music-specific (3). Cartesian modularism allows us to think of music as a fully generative phenomenon as long as the fully generative processes are not domain specific.

This consideration is closely related to another issue raised by JL, namely, that there is no similar structure in syntax to what they observe in the case of music. This is indeed the core claim underlying modular approaches to cognition. Yet this hypothesis is meaningful only in a particular context of the theory of linguistic syntax. If linguistic syntax is based on rules such as ‘S → NP + VP’, the argument remains compelling. Musical compositions are not formed out of noun phrases and verb phrases; sentences are not composed out of dissonant and consonant chord sequences. On the other hand, there is no longer agreement that recursion in syntax should be based on linguistically sui generis categories such as S, NP and VP. Although hardly an established fact, many linguists speculate that linguistic productivity could derive from a domain-general Merge. This operation applies rather automatically to music, while we agree that it still remains to be seen whether an elegant theory of musical syntax could be developed along these lines.

A similar argument is raised by Pinker and Jackendoff (2005). They point out that in addition to productivity, the syntax of natural languages involves several grammatical mechanisms, such as linear ordering of words (John loves Mary/Mary loves John), agreement (i.e., John sleeps/*sleep) and case (John saw him/*he), which are witnessed only in the case of human languages and are thus seen as language specific phenomena. Furthermore, they note that recursivity in the case of language differs from recursivity in other domains in several aspects (p. 230-231). According to Pinker and Jackendoff, the existence of such features calls for a “distinction between arbitrary recursive mathematical systems and the particular kinds of recursive phrase structure found in human languages” (p. 217).

While we agree with this conclusion, there being certainly many differences between linguistic and mathematical (and other) domains, the assumption that such differences must be explained by relying upon two different domain-specific generative mechanisms remains to be argued. Consider the case of syntactic cases in English, such as nominative (he) and accusative (him). To a first approximation, such cases are associated with phonologically overt nominal phrases at certain
syntactic configurations. Nominative case is associated with the position of grammatical subjects, while accusative case goes with the position of grammatical objects. In several models of grammar, the notions of “grammatical subject” and “grammatical object” are defined relative to a linguistic phrase-structure representation that is composed from language-specific entities, such as verb phrases, noun phrases, or tense projections, or perhaps from what is known as X-bar projections. The detailed properties of these representations do not matter for the present purposes, only the fact that such notions are usually more or less language specific. Since the linguistic representations that determine which case features (e.g., nominative or accusative) go to which syntactic positions are language specific, we have a compelling argument against the single source hypothesis based on linguistic case.

The whole line of reasoning hinges on the choice of the particular model of grammar. That is, the conclusion follows from the premise that the syntactic configurations determining the distribution of case features among noun phrases are defined by representations assembled by using a language-specific generative engine, for example, by rules such as $S \rightarrow NP + VP$ and $VP \rightarrow V + S$. What makes the single source hypothesis an interesting possibility to us is precisely the fact that theoretical linguistics is currently moving away from these assumptions and towards a model where the relevant syntactic configurations are not defined on the basis of absolute syntactic positions but, instead, on the basis of relative positions emerging from the bare phrase structure together with the properties of the lexical elements (Brattico & Huhmarniemi, 2006; Chomsky, 1995, 2006; Salo, 2003, pp. 93-122). For instance, nominal case is associated (assigned, checked or valued in the technical literature) with a noun phrase occurring in a local configuration with a certain grammatical head (e.g., at the “[Spec,TP] when T has the EPP feature,” to cite one influential proposal). It is then possible to explain the construction of the linguistic phrase structure tree by relying upon a domain-general Merge, as this process together with the lexical items is able to establish the required grammatical relations between various linguistic elements.

In the case of mathematics, it is at least conceivable that the recursiveness embedded in mathematical axioms derives its productivity from the same mental source as linguistic productivity (Chomsky, 1988, 2005b). As in music, it could be that the recursion that is written into the mathematical axioms and which is couched in terms of mathematical *sui generis* properties represents a cultural achievement rather than a psychologically realistic model of mathematical thinking. Indeed, it seems to us that the psychological data supports this interpretation. For instance, Gruber et al. (2001) reported a functional MRI study where they concluded that “the use of decomposition and recomposition strategies in more complex calculation problems does not rely on neuronal resources specific to mental arithmetic, but recruits left inferior frontal areas subserving language and working memory functions” (p. 358). This evidence is in striking agreement with the data discussed in
Section 3.4. Other studies have suggested that the primitive knowledge of numbers and their relations, what is sometimes called the “number sense,” is modularized and localized in the brain (Dehane et al., 1998). A fully generative mathematical competence could thus arise when the generative system and the more primitive number sense are connected with each other through an interface mechanism. There is some developmental evidence in favor of this hypothesis. Until children are about three years old, they master only a few number concepts, such as one, two and three, which generally become more inaccurate as the numbers become larger. The system is finite in the sense that those children are not capable of understanding counting ad infinitum. What they are able to do, in essence, is to distinguish groups of elements on the basis of their number. There is evidence that non-humans possess similar number concepts (Carey, 1998; Dehaene, 1997; Gallistel & Gelman, 2000; Hauser, Carey & Hauser, 2000). Between the ages of three and four, however, human children begin to understand the productive system of counting (Wynn, 1992), indicating that they have been able to link their generative capacity with the number sense. If so, then the acquisition of the link between the generative system (e.g., GAD) and the more modularized primitive systems would constitute a distinguishable cognitive event in its own terms.

One of the most interesting questions having to do with the single source hypothesis (to us, at least) concerns the relationship between syntax and semantics. In what sense does the strong single source hypothesis commit us to the extremely controversial claim that there is no difference between the two? Here again it is important to make a principled distinction between differences in the generative capacity and differences in the resulting representational systems. The distinction is important because the strong single source hypothesis commits us to the view that the productivity in syntax and the productivity in thought are based on the same computational mechanism, say Merge, but it does not commit us to the view that the two are based on the same representational system. This is because a representational system is constituted by its primitive elements, and presumably also by its interfaces with other cognitive systems, as much as it is constituted by its generative combinatorial syntax. The single source hypothesis leaves room even for the hypothesis that thought employs its own hierarchical representations, for instance, some form of basic argument-predicate relations, as long as these are finite and not generative.

Despite the possibility of reconciling the single source hypothesis with the thesis that syntax and semantics are based on different representational systems, the most elegant theory would attempt to combine the two into one. This proposal has been discussed recently in Chomsky (2006), Fodor (2003) and Bickerton (1995), who have at least speculated on the possibility that the interface between syntax and semantics, called Logical Form (LF) in some systems of grammar, could serve in the capacity of a generative representational medium for the language of thought. According to this view,
Logical Form then “represents thoughts rather than sentences” (Fodor, 2003, p. 157). Any such move would obviously bring us still closer to the single source hypothesis.

The preceding discussion aimed at showing that there is currently very little support for an outright rejection of Cartesian modularism. Cartesian modularism leaves us with non-generative modules, working alongside the domain-general generative system. The most interesting possibility is that these systems are based on finite-state computations, illustrated in section 2 (Figure 2). There is another possibility, namely, the hypothesis that such modules implement hierarchical representations without full productivity. Recall from section 2 that the symbolic theory of thought, which states that the human mind implements an algorithm that computes over symbols or hierarchical constituency structures, is conceptually and empirically distinct from the hypothesis which says that such representations are recursive, unlimited in their size and complexity. We can thus design a process that can assemble hierarchical representations without the capacity for recursion. To illustrate, suppose that we have rules which construct sentences $S$ from constituents such as NP and VP (1a), but which do not contain a recursive clause that would embed another sentence as the complement of the verb inside of the VP (1b). The speakers of this language could form simple sentences containing agents, patients and verbs, such as *Mary loves John*, but they could neither say nor understand a sentence such as *Tim thinks that Mary loves John* which contains two sentences, one being embedded recursively within the other. In fact, although the matter is controversial, this is precisely what Everett (2005) claimed characterizes Pirahã, a language spoken by the members of a small, relatively isolated tribe living in the west Amazon.

4.4 Localization

Another objection against the single source hypothesis concerns lesion data. Although neuroscientists have begun to associate frontal areas, especially Broca’s area, to the generative capacity of the human mind, there is as of yet no evidence that a lesion in a single brain area is able to knock out that capacity from all cognitive domains. This poses a challenge to the single source hypothesis, which seems to suggest that by disturbing the normal functioning of that source, whatever that is, the human mind should lapse into an all-encompassing non-generative state. Nothing of the sort has been observed to our knowledge, and it is certainly doubtful whether such a source will be ever found.

We think that these considerations show without doubt that the single source hypothesis cannot be developed in this respect along the lines of Descartes, who would perhaps have thought that the disconnection of the human soul from the gland would have left the human body to behave like a reanimated human corpse, responding mechanically to stimuli and uttering sounds in an utterly non-
creative way. Recall that the single-source hypotheses defined in Section 3 were formulated in cognitive nomenclature. GAD or the Cartesian mind, for instance, were abstract cognitive mechanisms whose implementation was not specified in neural terms, save some speculations concerning their localization. But the debate concerning the localization of cognitive operations masks the fact that very little is known about how cognitive processes are implemented in the human brain. There are several hypotheses concerning the role of Broca’s area alone. An additional complication here is that it is well documented that the different regions of Broca’s area may serve different cognitive functions (Müller & Basho, 2006), that the localization of cognitive functions in normal adults results in developmental specialization (see, e.g., Borgstein & Grootendorst, 2002) and that lesions in Broca’s area do not necessarily lead to a loss of productivity in other domains, such as mathematics. Concerning the latter point, specifically, Varley et al. (2005) provided striking evidence of patients with large left-hemisphere perisylvian lesions which were associated with severe grammatical impairment but an apparently intact ability to process hierarchical representations in the domain of mathematics. The authors conclude that the recursiveness in language cannot serve as the basis for recursive computations in mathematics. However, the authors point out that the single source hypothesis, as developed in the present article, would still be compatible with this (and similar) data because it is possible that both language and music use one neutral, domain-general generative engine, and that mathematical processes “gain direct access to this system without translation into a language format” (p. 3523). Thus, according to the current evidence, it makes little sense to localize the single source in one region in the brain; rather, as suggested by Ullman (2004), the ability to process hierarchical representations may be a special property emerging from the organization of certain kinds of neuronal networks.

To summarize, two central arguments emerge from this discussion. The first concerns the distinction between the strong single source hypothesis and the weak single source hypothesis, where the latter hypothesis is immune to all the objections we have seen so far. This version represents a compromise between two compelling observations, namely, that there are independent domain-specific generative systems and that they all cluster in one species. The second argument concerns the observation that the domain specificity of various cognitive domains and cognitive dissociations does not pose as strong an obstacle to the strong single source hypothesis as is perhaps often thought. Specifically, this hypothesis leads to what we called Cartesian modularism, which agrees that a large amount of knowledge may be modularized in the human brain, but it disagrees with the contention that such modularized knowledge in itself is generative.

5. Conclusions
To summarize, the Cartesian theory of productivity has not survived without criticism. Much of this criticism comes down to the modular conception of productivity, which attributes various kinds of domain-specific generative engines to the human brain. The motivation for this view must be empirical since the hypothesis is remarkably complex, entailing a unique generative system for each domain in the worst case. But is there strong evidence in favor of this complex hypothesis? The main motivation for the single source hypothesis stems from the fact that the evidence is not as clear as we perhaps used to think. In linguistics, for instance, the bare phrase structure hypothesis with strong lexicalism lessens the pressure on language-specific productivity. In music, no robust empirical evidence shows that domain-specific musical syntax could not be based on relatively local computations. Whether or not the Cartesian theory eventually turns out to be true, it will certainly continue to produce new research and findings.
References


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1 Chomsky’s earlier formulations of the generative grammar were less modular in their orientation if compared to the *Aspects* model (Chomsky, 1965). For instance, one early work (Chomsky, 1955) relied on *generalized transformations* in explaining productivity, and this notion in fact resembles the more recent models discussed later in this paper in connection with non-modular theories of productivity. This is why we think it is safe to attribute the thesis of modular linguistic productivity to versions of the generative grammar that were formulated in the early 60s, but not earlier. How Chomsky and others viewed the matter prior to this data, if the matter was explicitly addressed at all, must be sought from the authors themselves as the linguistic literature written in the 50s does not to our knowledge address this matter explicitly.

2 This is an idealization. It is important to keep in mind that in evolutionary terms several of these interfaces, such as those having to do with, e.g., abstract mathematics, writing systems, and advanced systems of musical composition, have been realized only after a certain level of cultural achievement was in place.

3 The lexicon is here seen as a finite list of morphemes, the smallest packages of meaning and form. For instance, the word *walked* contains two morphemes, [walk] and the past tense suffix [ed].

4 Simultaneously, the explanatory burden of the lexicon and other parts of the grammar, namely the interfaces between recursion and other cognitive domains, is increased. The assumption that the derivation is controlled in large part by the properties of the words, rather than the generative rules, is called ‘strong lexicalism’ in recent linguistic literature.

However, Friederici et al. (2006a) do not claim that hierarchical computations are instantiated exclusively in Broca’s area; rather, they claim that hierarchical computations are “supported” (p. 2458) by Broca’s area, which we take to mean that these neuronal networks are at least necessary for implementing hierarchical computations in various cognitive domains. Musso et al. (2003) speculated that while Broca’s area is specialized in the processing of syntactic hierarchies, “it could well be the case that the hierarchical structure is typical but may not be specific for language” (p. 778). Additional brain regions associated with phrase-structure building seem to involve at least the left anterior supra temporal gyrus (Grodzinsky & Friederici 2006).

By complex calculation they mean multiplication and division complex enough that the subjects could not pull the answers out of their memories (i.e., $3 \times 18$).

According to two recent reviews concerning the function of Broca’s area (Grodzinsky, 2000; Stowe et al., 2005), the traditional model in which Broca’s area was seen as a general language production organ has been evolved into quite specific hypotheses concerning its linguistic function. For instance, the region could be involved in implementing syntactic processing more generally (Embick et al., 2000) or more specific syntactic processes, such as transformations (Ben-Shachar et al., 2003; Grodzinsky 2000), linearization (Bornkessel et al., 2005; Grewe et al. 2005) or syntactic working memory functions (Fiebach et al., 2001; 2002, Fiebach et al., 2005, Friederici et al., 2006b, Stowe 2000). However, some authors do not think that Broca’s area is responsible for linguistic computation only; rather, they speculate that the region involves more domain-general computations. According to one such view, it implements general working memory functions (Cabeza & Nyberg, 2000). The second view says that it serves the computation of hierarchical processing in all, or several, domains (Brown et al., 2006, Friederici, 2004, Friederici et al., 2006a, b, Semenza et al., 2006, Tettamanti & Weniger, 2006; Ullman, 2004). While the aforementioned studies have each appointed some distinct computational role for Broca’s region, it may also be that it only plays a distinctive part when participating in some cortico- or thalamo-cortical network (Heim et al., 2003; Ullman, 2004; 2006). Finally, it should be noted that the findings and hypotheses about the function of Broca’s area approximate some standard functional brain structure that may not exist. It is widely acknowledged that the general principles of plasticity affect functional brain structure during development and recovery, so sometimes linguistic skills lateralize to the right instead of the left hemisphere (Demonet et al., 2005; Musso et al., 1999). Also, a more radical example of hemispherectomy patients reveals that each hemisphere is capable of taking over all sensory and cognitive functions (e.g., in Borgstein & Grootendorst, 2002).
John believes that the dog chased the cat.
John believes that the dog...

Mary wonders

Bill the red small big...
John believes that the dog chased the cat