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Merge Does Not Trigger a n + 1 Recursive Function: A Reply to Mendivil-Giró (2025)

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Abstract

This article examines the claim that the recursive operation Merge underlies the generative structure of the natural number system. I argue that this claim rests on a conflation between recursion as a property of syntactic representation and recursion as a property of numerical computation. In syntax, repeated applications of Merge yield hierarchically structured expressions; in arithmetic, the successor function yields successive values. These are not the same kind of operation. Focusing on recent proposals by Mendívil-Giró (2025) and Watanabe (2017), I show that Merge, whether external or internal, does not by itself derive numerical succession, but only structured symbolic objects whose interpretation must be independently determined. I further argue that the principal assumptions needed to sustain a Merge-based theory of natural number (innate numerical generativity, hierarchical structure in the count list, and a primitive lexical item corresponding to 1) lack independent empirical support. I conclude that number generativity is better understood as an emergent property of compositional symbolic structure than as the direct output of a successor-like operation implemented by narrow syntax.

Keywords

Merge, recursion, successor principle, natural numbers, categorical recursion

1 Introduction

The acquisition of natural numbers has long been a central problem in cognitive science, raising fundamental questions about how humans come to represent exact numerical concepts, move beyond approximate quantity representations, and construct systems capable of unbounded generativity (Carey, 2009; Carey & Barner, 2019; Dehaene, 1992;

Dehaene et al., 2025; Gallistel & Gelman, 1992; Piaget, 1965; Rips et al., 2008; Spelke, 2017). Although natural numbers constitute one of the most familiar systems in human cognition, children require many years to acquire both their meaning and their generative properties (Fuson, 1988; Gelman & Gallistel, 1978; Le Corre & Carey, 2007; Sophian, 2017; Steffe et al., 1983; Wynn, 1992). Moreover, in some populations with limited symbolic number systems, a fully generative concept of number may never be achieved (Pitt et al., 2022). A core challenge lies in explaining how some humans populations come to understand that numbers form a rule-governed system capable of generating indefinitely distinct values. Traditionally, psychological (Cheung et al., 2017; Izard et al., 2008; Leslie et al., 2008; Schneider et al., 2021) and linguistic (Mendivil-Giró, 2025; Watanabe, 2017; Yang, 2016) theories have attributed this conceptual breakthrough to the acquisition of the successor principle, the idea that every natural number has a successor that is exactly one greater (Peano, 1977). However, despite its prominence, it remains unclear whether the successor principle constitutes a psychologically real mechanism or merely a formal description imported from mathematics (Guerrero & Park, 2023; Hiraiwa, 2017; Relaford-Doyle & Núñez, 2018).

Most existing accounts implicitly assume an isomorphism between the structure of natural numbers and the cognitive processes that underlie their acquisition (Gallistel & Gelman, 1992). Because the natural numbers are defined axiomatically via a successor function, it is often inferred that humans must possess or develop a successor function to generate new numbers. This inference, however, conflates formal definitions with cognitive mechanisms. As recent theoretical work has argued, even though the successor principle is indispensable for some axiomatic definitions of number, it is poorly specified as a psychological construct, difficult to operationalize empirically, and insufficient to explain cross-linguistic and developmental variation in number acquisition (Guerrero & Park, 2023).

Mendivil-Giró's (2025) central claim is that the recursive operation Internal Merge (IM), when applied iteratively to a primitive representation of one, implements the successor function and thereby grounds arithmetic. The present reply argues that this claim fails for a principled reason: Internal Merge generates hierarchical structure, whereas the successor function is a value-generating operation over numerical magnitudes. Before introducing the discussion about the relation between IM and the successor function, I first provide some context on the role of the successor principle in the theories of number acquisition, as well as on recent approaches that propose a connection between recursion in language and recursion in number.

2 The Successor Principle as the Core of Number Concepts

Many theories have turned to the successor principle as the key to understanding number acquisition. Formally, the successor principle states that for any natural number n, there exists a successor $n + 1$, and that repeated application of this function generates the entire set of natural numbers. This idea is central to formal axiomatizations of arithmetic, such as the Dedekind–Peano axioms (Peano, 1977).

Some theorists have proposed that humans possess an innate mechanism that generates integer representations via a recursive successor function (Leslie et al., 2008). Others argue that children acquire the successor principle through inductive inference over counting sequences (Carey & Barner, 2019; Le Corre & Carey, 2007), particularly once they understand the cardinality principle, that the last word in a count indicates the size of a set.

Despite its prominence, the successor principle raises several unresolved problems. First, it is unclear how children acquire a recursive, self-referential function from limited and finite experience. Second, the successor principle is often conflated with counting-related abilities, such as knowing the next word in a count list or adding one to small numbers. Third, it is not obvious how to measure abstract knowledge of the successor principle independently of counting skill or familiarity with specific number ranges.

2.1 Innateness, Induction, and the Limits of Successor-Based Accounts

Leslie et al. (2008) propose that humans possess a cognitive mechanism, called the integer symbol generator, that underlies the representation of natural numbers. According to this account, numerical cognition is grounded in two core primitives: a representation of the number 1 and a operation that computes $n + 1$. Together, these components instantiate a generative system equivalent to the Dedekind–Peano axioms, which formally define the natural numbers as an infinite sequence generated recursively from a base element. On this view, the successor principle is not learned but is part of the initial cognitive architecture. Developmental change primarily involves linking culturally transmitted numeral systems and counting procedures to pre-existing internal representations of integers. The appeal of this hypothesis lies in its formal elegance: it provides a direct psychological counterpart to the mathematical definition of number and explains numerical infinity as a consequence of recursive symbol generation.

In contrast, Carey's theory of Quinean bootstrapping (Carey, 2004, 2009) proposes that numerical meanings are constructed through inductive learning over initially non-numerical representational systems. Children first map a small subset of number words (e.g., one, two, three) onto exact set representations supported by parallel individuation mechanisms (Carey & Xu, 2001). At the same time, they acquire an ordered count list whose elements initially lack semantic content. Through comparison of these two systems, children infer that successive number words correspond to sets that differ by one element (Le Corre & Carey, 2007). This inductive insight gives rise to the cardinality principle: the understanding that the final word used in counting denotes the cardinal value of the entire set. Once this principle is acquired, children rapidly extend numerical meanings to previously meaningless count words. On this account, successor knowledge emerges through semantic induction rather than innate specification.

Although both theories appeal to the successor principle as central to numerical cognition, they differ fundamentally in how that principle is assumed to arise. Leslie et al.'s account treats the successor relation as an innate component of the cognitive system, whereas Carey's account treats it as the outcome of inductive learning over small-number representations and an ordered counting sequence of cardinal numbers.

The primary weakness of the integer symbol generator hypothesis is its lack of empirical support. Cross-linguistic and anthropological evidence shows substantial variation in how, and even whether, exact number concepts are represented across cultures (Comrie, 2013; Corbett, 2000; Hurford, 1975). Some numeration systems lack exact representations of one (Pica & Lecomte, 2008), and many restrict exact cardinality to small numbers without developing a generative counting system (Comrie, 2013; Corbett, 2000). Developmentally, children who can recite long count lists often fail tasks that require explicit $n + 1$ reasoning outside of rote counting contexts (Schneider et al., 2021; Spaepen et al., 2018). These findings are difficult to reconcile with the existence of an innate, unbounded successor mechanism.

Carey's bootstrapping account is better supported empirically and provides a compelling explanation of early developmental phenomena, including subset-knower stages and the acquisition of the cardinality principle. However, it faces a different limitation: the inductive processes it describes do not yield the successor principle in its formal sense. Evidence from successor-sensitive tasks indicates that children's understanding of $n + 1$ relations is fragile, range-bound, and develops gradually, even after mastery of counting procedures (Cheung et al., 2017; Davidson et al., 2012; Schneider et al., 2021; Spaepen et al., 2018). Thus, acquiring the cardinality principle does not entail an understanding of the natural numbers as a recursively defined, infinite system.

Taken together, these critiques suggest that neither theory fully explains how children come to represent the generative structure of the natural numbers. Leslie et al.'s proposal offers formal adequacy without empirical plausibility, whereas Carey's account offers empirical grounding without a clear mechanism for the emergence of numerical generativity. This tension highlights the need for a revised theoretical framework that explains how abstract successor knowledge is constructed over development, rather than assumed as either an innate primitive or the direct product of early induction. This limitation suggests that the problem may lie not only in how the successor principle is learned, but also in how recursion itself is conceptualized in theories of number acquisition.

2.2 Recursion Reconsidered: Numbers vs. Cardinal Numbers

Barner (2017) has proposed that children acquire the successor principle through inductive inference over the counting sequence. According to this account, children detect regularities in number words, particularly the productive decade + unit rule, and learn that local successor relations (e.g., *forty-two* follows *forty-one*) can be extended across decades (e.g., *fifty-two* follows *fifty-one*). Through repeated exposure to these regularities, children are argued to move from item-based successor mappings to generalized successor knowledge, corresponding to the successor principle (see also Schneider, Pankonin, et al., 2021).

Support for this proposal comes largely from studies using rote counting tasks, which show that children who demonstrate greater facility with these regularities, such as those who can count close to *one hundred* or who can extend counting beyond decade boundaries with minimal support, also perform better on tasks probing numerical infinity or broader numerical knowledge (Cheung et al., 2017; Chu et al., 2020). Based on these associations, proponents argue that learning the structural regularities of number words triggers the acquisition of the successor principle.

While this inference is intuitively attractive, it rests on a conceptual assumption: that the regularities in cardinal numbers are equivalent to the recursion defined by the successor function in the formal theory of natural numbers. This assumption is rarely made explicit and is seldom examined. Consequently, the observed relations between counting proficiency and performance on tasks related to numerical infinity do not, by themselves, establish that children have acquired a generalized successor principle. Instead, they are equally compatible with the alternative possibility that children are exploiting regularities in a symbolic system without representing or deploying a recursive successor operation at the conceptual level. Disentangling these possibilities requires a careful distinction between different notions of recursion and a reassessment of what exactly counting based induction can and cannot support.

Theoretical analyses converge on the conclusion that recursion is not a unitary concept (Hauser et al., 2010; Lobina, 2011, 2014, 2019; Martins, 2012; Tomalin, 2006, 2007, 2011; Watumull et al., 2014).[1] At minimum, two fundamentally different definitions must be distinguished. The first is recursion as self-reference (Lobina, 2014, 2019; Soare, 1996; Tomalin, 2006), characteristic of logico-mathematical systems (Soare, 1996). In this sense, recursion is a property of a function: a process that applies to its own output. It requires two elements: values calculated in a previous step and the self-calling of the function

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1) Some of these authors make a stronger claim, arguing that recursion is widely misunderstood and that the only adequate definition corresponds to the notion of a self-referential function (Lobina, 2014; Watumull et al., 2014).

itself. The successor function in the Peano axioms exemplifies this definition, as each number is generated by repeatedly applying the same function to a previously generated value (e.g., 3 = S(S(1))). This form of recursion is procedural, operational, and intrinsically generative.

The second definition characterizes recursion as self-embeddedness, a property of representational structure rather than computation. In linguistic theory, for some authors categorical recursion arises from hierarchical syntactic embedding, typically analyzed as the result of repeated applications of Merge (Berwick & Chomsky, 2016; Chomsky, 2005, 2014; Chomsky et al., 2023) and labeling operations (Cecchetto & Donati, 2015; Donati & Cecchetto, 2011). Merge is a self-referential mechanism that builds hierarchically structured expressions. Merge takes the syntactics objects α and β and forms the set {α, β}. The output δ (i.e., {α, β}) is further capable of merging with a new syntactic object γ to form the set {γ, δ} (i.e., {γ, {α, β}}). Labeling is the algorithm that assigns a label to syntactic objects. Categorical recursion in this context occurs when a syntactic object of one label is embedded in a syntactic object with the same label either directly or via another syntactic object with a different label. Here, categorical recursion consists in a structure of category embedding (e.g., a Number phrase embedded within another Number phrase, see Hollebrandse & Roeper, 2014; Pinker & Jackendoff, 2005; Roeper & Oseki, 2018; Roeper & Snyder, 2005), not in a function that computes successive values. Importantly, self-embeddedness characterizes how expressions are organized, not how new elements are generated by computation.

Barner's proposal implicitly assumes that discovering self-embedded structure in complex numerals, such as the hierarchical organization of cardinal numbers (Hurford, 1975, 1989, 2007), leads children to acquire the self-referential successor function that defines natural numbers. However, this inference is unwarranted. Categorical recursion in cardinal numbers encodes additive relations (e.g., [[two hundred] two] as 200 + 2), not successor relations. The hierarchical structure of numerals corresponds to compositional arithmetic operations, not to repeated applications of the successor function. Thus, the recursion present in numeral structure is different from the recursion that defines the natural number system. As a result, Barner's account appears to conflate categorical recursion as a property of linguistic representation with recursion as a property of abstract numerical computation. The proposal assumes, without independent justification, that exposure to self-embedded numeral structures can trigger the acquisition of self-referential successor function. This assumption remains underdeveloped theoretically and currently lacks strong empirical support.

2.3 External and Internal Merge and the Successor Function

Mendivil-Giró (2025) has proposed a new development in the relation between the recursive machinery used to produce language (i.e., Merge) and the recursive function used to produce natural numbers (i.e., successor function). He states that the mechanism that supports the successor function is Internal Merge (IM), assuming that the syntactic element that is copied is the primitive numerical representation of one (1–4)

(1) [one] corresponds to the primitive natural number 1, externalized as *one*

(2) [one one] corresponds to natural number 2, externalized as *two*

(3) [one [one one]] corresponds to natural number 3, externalized as *three*

(4) [one [one [one one]] corresponds to natural number 4, externalized as *four*

According to Chomsky et al. (2023) in one of the most recent formulations of Merge, syntactic derivations begin with lexical items drawn from the Lexicon, which constitute the basic atoms of syntactic computation. These items are introduced into a workspace (WS), where they are combined by Merge to form hierarchically structured objects. The resulting structures are then transferred to the interface systems—the sensorimotor (SM) system, responsible for externalization, and the conceptual–intentional (CI) system, responsible for interpretation.

Following this characterization, Mendívil-Giró's primitive concept of one must initially be part of CI system. There is evidence that young children represent small quantities (Lipton & Spelke, 2004; Starkey et al., 1990; Xu et al., 2005) suggesting that it is reasonable state that the representation of exactly 1, or something similar, is part of the human mind even before the lexical item used to express it is available. Additionally, there is evidence that most human populations use a word that represents the idea of exact 1 (Comrie, 2013; Corbett, 2000; Da Silva-Sinha et al., 2017; Hurford, 1989).[2] Therefore, the acquisition of the lexical item that represents the exact value of 1 must be the first requirement to support his idea. Having the lexical item for 1, the components of the proposal are completed. The lexical item *one* could introduce into the WS and IM could make copies of it to produce the natural numbers.

A crucial ambiguity in the proposal concerns the status of the element copied by Internal Merge. It is never specified whether IM copies a lexical item (*one*), or a pre-lexical conceptual representation of exactly 1. This distinction is crucial: if IM copies a lexical item, the derivation merely duplicates a symbol without incrementing numerical value; if it copies a conceptual unit, then a successor operation is presupposed rather than derived. In either case, Internal Merge cannot implement the successor function, it either produces duplication or tacitly assumes numerical succession.

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2) According to Pica and Lecomte (2008), the Mundurucú numeration system lacks a precise concept of exact one. In this system, the cardinal number word *pug* does not denote an exact singular quantity but instead refers to an approximate magnitude centered around one.

From this perspective, Mendívil-Giró's proposal presupposes that the concept of one works as a syntactic primitive that can be repeatedly copied and remerged independently of any compositional structure or lexical differentiation. This assumption is problematic for at least two reasons. First, it conflates syntactic copying with numerical incrementation, assuming that repeated Internal Merge over a single lexical item yields successor relations, rather than mere structural duplication. Second, it abstracts away from the fact that natural languages do not externalize numerals as repeated instances of one but instead rely on distinct lexical items and hierarchical compositional rules to encode numerical values (Hiraiwa, 2017).

More generally, deriving the successor function from Internal Merge presupposes that syntactic self-embedding can directly implement a self-referential numerical operation. Yet, as argued above, hierarchical structure in syntax is a property of representational structure, whereas recursion in the Peano axioms is a property of functions over values. Internal Merge produces structural depth, not numerical increment. The successor function, by contrast, is defined over values and requires a mapping from n to $n + 1$. Structural embedding does not, by itself, specify such a mapping. Consequently, even if numeral expressions are produced by a recursive function, this recursion is orthogonal to the recursion that defines the natural number system.

Another possibility that has been proposed is that Merge underlies the representation of the natural number sequence. According to Watanabe (2017), natural numbers can be represented as recursively generated set-theoretic objects produced by Merge. On this view, what people acquire is not the natural number concept itself, but the linguistic mapping that connects these representations to the count list and to numeral forms. Watanabe argues that recursive application of Merge to an arbitrary lexical item (*i* in 5) yields set-theoretic objects corresponding to natural numbers, as in (5). These representations are mapped onto an initial segment of the count list through linearization (6), while the cardinal principle is derived by deletion rather than stipulated independently (7).

(5) set-theoretic representation; 1 = {*i*}; 2 = {*i*, {*i*}}; 3 = {*i*, {*i*, {*i*}}}

(6) linearized count sequence; 1 = one; 2 = one, two; 3 = one, two, three

(7) cardinal output after deletion; 1 = one; 2 = ~~one,~~ two; 3 = ~~one, two,~~ three

For Watanabe, the semantic representation in (5) is innate and generated by the linguistic operation Merge, but children must still acquire the computational mapping that links these representations to the count list and to cardinal numeral forms. For this approach to be plausible, the linguistic representation of the count sequence must be hierarchical after linearization, since the count list requires precedence relations and the derivation of the cardinal form requires constituency. On this account, the cardinal value is obtained by deletion of the highest constituent within the linearized hierarchical structure.

This is an interesting proposal with considerable internal logical coherence. However, three of its central assumptions remain empirically underdetermined. First, it assumes that the internal representation of natural numbers, together with its generative capacity, is innate. Second, it assumes that the count sequence for the cardinal numerals below ten is hierarchically represented, such that deletion can derive the cardinal form from the linearized structure. Third, it assumes that some lexical item that represents 1 is an innate representation. Its explanatory value therefore depends on whether these assumptions are independently justified.

Regarding the first assumption, there is no direct evidence against it. Even though some populations lack number systems based on exact increments of one (Pica et al., 2004; Pica & Lecomte, 2008), many languages have number systems restricted to small quantities that do not appear to exhibit generativity (Comrie, 2013; Corbett, 2000; Da Silva-Sinha et al., 2017), and exact quantity representations seem limited in the absence of number words (Frank et al., 2008, 2012), it remains possible that some internal representation of natural number exists without being externally expressed. Thus, the cross-linguistic and developmental evidence does not provide positive support for the innateness of natural number representations, but neither does it conclusively rule out the possibility that such representations exist without being fully externalized in language.

Regarding the second assumption, a consecutive linear sequence such as one, two, three cannot be taken as evidence for hierarchical structure, since linear order is compatible with both flat and hierarchical representations. Demonstrating hierarchy requires independent evidence of constituency or asymmetric structural relations. Moreover, from the perspective of numerical meaning, simple cardinal numbers belong to the same semantic class: they denote units rather than higher-order bases such as tens, hundreds or thousands. For that reason, there is no obvious semantic motivation for imposing hierarchical structure on the count list below ten. Without independent evidence for such hierarchy, the deletion analysis appears to be motivated by the theoretical requirements of the proposal rather than by independently established properties of the count sequence.

A further difficulty concerns the status of the primitive element (*i* in 5) that serves as the input to Merge. Similarly to Mendivil-Giró (2025), the status of the item that represents 1 remains unclear. Although Watanabe treats it as a lexical item, as required by the operation Merge, the result of recursively applying Merge to it is equivalent to a set-theoretic definition of the natural numbers. It is therefore not clear whether this element should be understood as a genuine lexical item, a semantic primitive, or a formal placeholder required by the analysis. This concern is reinforced by the fact that developed numeral systems do not typically build numerical expressions through overt repetition of 1. As noted above, developed number systems do not typically rely on repetition of the lexical item for 1 to encode the successive addition of 1. The developed number systems that show some reuse of the sign for 1 are found in certain sign languages, and similar patterns also appear in notational systems such as tally marks for the representation of small quantities. However, in spoken systems restricted to small quantities, a lexical item for 2 is often also available, and reduplication of 2 is frequently used to represent 4. This suggests that symbolic representations based explicitly on repetition of 1 are more characteristic of visually grounded formats than of spoken numeral systems. This typological pattern does not rule out an internal primitive corresponding to 1, but it weakens the claim that natural number representations are linguistically built through overt or lexically grounded repetition of that element.

Thus, while proposals that link numerical cognition to the mechanisms of linguistic recursion are theoretically intriguing, accounts that equate Merge, whether external or internal, with the successor function risk collapsing distinct notions of recursion and obscuring the representational basis of numerical meaning. Any account that derives arithmetic from Merge must therefore explain how a syntactic operation acquires numerical semantics, rather than assuming that structural repetition automatically yields quantitative succession.

3 A Structure-Based Alternative to Successor-Driven Generativity

An alternative account of numerical generativity does not require deriving the successor function from syntactic operations. On a structure-based view, generativity emerges from the acquisition of hierarchically organized symbolic representations whose interpretation is governed by compositional arithmetic rules, rather than from an internal operation that computes $n + 1$. Numeral systems encode additive and multiplicative relations directly in their structure (e.g., three hundred two = 3 × 100 + 2), and once these compositional rules are mastered, the system is generative by closure: finite lexical resources combined through recursive structure yield an unbounded set of exact numerical expressions. On this view, categorical recursion in numerals is a property of representation, not of a value-generating function, and numerical infinity is an emergent consequence of symbolic composition rather than the output of a successor mechanism. Crucially, this account explains why numerical reasoning can extend beyond rote counting, why numerical difficulty tracks syntactic complexity rather than magnitude, and why cross-linguistic variation in numeral structure shapes developmental trajectories, without assuming that syntax itself implements numerical succession.

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