Understanding "Compositionality" in Research on Language Emergence

Wiktor Rorot (w.rorot@uw.edu.pl)
Human Interactivity and Language Lab, Faculty of Psychology
University of Warsaw, Poland

Joanna Raczaszek-Leonardi (raczasze@psych.uw.edu.pl)
Human Interactivity and Language Lab, Faculty of Psychology
University of Warsaw, Poland

Abstract

The goal of this paper is to analyze the notion of "compositionality" and its use in contemporary cognitive science. We argue that the concept has undergone a series of apparently minor definitional shifts since its initial inception within the field of philosophy of language (as indicated by Janssen, 2012). These changes result in a divergent meaning of the term as it is used in the emergent communication and language evolution communities. Hitherto, this fact has been underappreciated, whereas we believe that it has significant implications for understanding the nature of syntax and the sources of linguistic and conceptual structure. We argue that originally, "compositionality" was understood as pertaining primarily to the process of understanding a compound utterance by a hearer. Other scholars, however, take it to be a prerequisite of the structure of languages. In all contexts, investigating compositionality of natural languages requires making a host of idealizing assumptions. For this reason, we propose to understand compositionality as just one idealized principle influencing the construction of compound expressions in language, necessarily complemented by other principles. This allows for appreciating the structural entanglements permeating natural language and opens new avenues for accounting for them.

Keywords: compositionality; language emergence; language evolution; emergent communication; syntax; semantics;

Introduction

The notion of "compositionality" has traveled a winding path from its initial inception in philosophy of language, which is traditionally traced to Gottlob Frege, through linguistics, to its contemporary use within the fields of artificial intelligence and emergent communication. It is considered "a fundamental presupposition of most contemporary work in semantics" (Szabó, 2020) and makes an important appearance also in the fields of syntax, philosophy of mind, and neuroscience to list only those included in a recent, comprehensive handbook (Werning, Hinzen, & Machery, 2012). These disciplines begin with formal definitions of the concept, which share the same core, but differ in some usually overlooked and apparently minor details, which eventually lead to significantly divergent understanding and uses of "compositionality".

In the current paper, we would like to discuss the role that compositionality has played in recent research within the fields of language emergence and language evolution. These communities take compositionality present in modern natural languages for granted and investigate possible evolutionary trajectories in the history of (pre)linguistic communication which might have led to the emergence of this property (e.g., Nowak, Plotkin, & Jansen, 2000). At the same time, they treat compositionality as a uniform phenomenon, placing an even greater premium on the task of explaining its origin. We want to highlight that this in fact shifts the concept significantly from its original role and, combined with a host of idealizing assumptions required by formal definitions of compositionality, puts the implied role of the property, as the main source of structure in natural languages, under doubt.

We argue that it is more meaningful to regard compositionality as an idealized principle which can account for only some structural properties of language. As such, it is fruitful to include the contrasting properties of contextuality and holism (and possible others) to be able to explain the complexity of natural languages. In the remainder of this paper we show how these contrasting principles emerge from distinct perspectives of different research fields—what we call compositionality on the "level of meaning" and on the "level of form"—and sketch how they can be connected to provide a fuller account of linguistic and conceptual structure.

Compositionality on the "level of meaning"

The sources of the principle of compositionality can be traced back to the early nineteenth century,[1] however most often it is attributed to Gottlob Frege, who discussed two opposed principles that as a matter of historical accident both became known as *Frege's principle* in different research communities. As the analysis of (Janssen, 2012) indicates, in fact only the *principle of contextuality* has been explicitly formulated by Frege: "Never ask for the meaning of a word in isolation, but only in the context of a proposition." (Frege, 1960, p. xxii).

This has been the favored approach to the semantics of compound expressions for Frege in his earlier work, however in later publications he has shifted his position more in favor of the *principle of compositionality*. Although he does not explicitly formulate the latter principle, we may mirror the phrasing of the original *Frege's principle* (i.e., of contextuality), in order to highlight the contrastive character of compositionality: *Never ask for the meaning of a proposition, but only as a function of meanings of words which compose it* or more along the lines of the dominant contemporary phrasings of compositionality (although Szabó (2012) notes important ambiguities in this standard approach): "The mean-

[1] The historical discussion in the current paper follows closely (Janssen, 2012; Kracht, 2012; Szabó, 2020).

In M. Goldwater, F. K. Anggoro, B. K. Hayes, & D. C. Ong (Eds.), *Proceedings of the 45th Annual Conference of the Cognitive Science Society.*

ing of a compound expression is a function of the meanings of its parts and of the way they are syntactically combined." (Partee, 2004, p. 153)

The important element that we wish to highlight in this version of the principle of compositionality is that it is primarily concerned with the *meaning* of compound expressions and its parts (sentences or propositions, and words). This places compositionality primarily on the semantic level, or—if an account such as the one put forward by Horwich (1997) is considered—an interface between semantics and pragmatics, which takes into account also the process of interpretation and understanding of an utterance.[2]

What we mean by this is that compositionality on the level of meaning focuses on the interaction of the *meanings* of parts and wholes of compound expressions. Consider the example of regular verbs, such as in the English Past Simple tense. In this case, the infinitive form of a verb, which we may take (for the purpose of the argument) to mean or refer to a particular action, e.g., 'to plant', is simply attached to the suffix '-ed', which we may take to mean or refer to the past nature of an action. The meaning of the compound, 'planted', is also quite simply this particular action being executed in the past: a combination of the component meanings.

The reference to the syntactic combination of meanings in Partee's formulation above is important, but much weaker than in other research fields (see next section). It amounts to a specification of the proper function for the combination of the meanings of the parts. This is more explicit in the formalization of the concept which draws from Montague (1970; see: Kracht, 2012). Montague takes the meaning of a compound expression to be compositional just in case there exists a partial function on the domain of meanings, such that the meaning of the compound expression is equivalent to the output of this function on the meanings of the parts of the expression. In layperson's terms, this amounts to a requirement that the syntactic structure of the compound expression should prescribe a corresponding function in the domain of meanings of parts of the expression.

In the result, properties of the syntactic structure are assumed or bracketed in this approach, and the focus is placed on the meanings of words—parts, and utterances—compound expressions made from those parts. For this reason, we will call this perspective "compositionality on the level of meaning," to highlight the differences with the approach discussed in the next section.

As mentioned above, compositionality on the level of meaning, especially as formalized by Montague, requires several assumptions. Most importantly, it requires that the set of meanings be precisely defined and, furthermore, that there be a *homomorphic*, i.e., structure-preserving, mapping between expressions and meanings (Szabó, 2020). This is a strong requirement, since it presupposes that these structures (expressions and meanings) are algebraic and have an underlying set. If we take this framework literally, the logical nature of expressions, which need to be truth-evaluable, is inherited by meanings, as they have to be of the same type. We can only consider meanings as logical objects: sets, sets of sets, etc. This is incompatible with important strands of contemporary thinking in psychology and cognitive science, most notably from the perspective inspired by ecological psychology and enactivism, which take meanings to be lived, interactive, embodied and embedded in the physical and biological world (Thompson, 2010; Di Paolo, Cuffari, & De Jaegher, 2018; Raczaszek-Leonardi & Kelso, 2008), and not abstract, logical objects. These ecological meanings can be at best *represented* as a codomain of such homomorphic mapping, although one can argue that even this cannot be done appropriately, as homomorphism requires temporal stability which is hard to come across in interactions. Effectively, within the framework of Montague, compositionality can be considered only in the case of disembodied, logically sterile meanings. This strong requirement is most often lifted and instead meanings are treated precisely as being *represented* by those specific logical objects, a far more relaxed condition. This weakens significantly the argument advanced here, but reduces also the strength of the principle of compositionality, rendering it purely instrumental, as it only describes our descriptions of language, not language itself.

Compositionality on the "level of form"

The language evolution research community takes a slightly different perspective on what is meant by "compositionality." In this context, compositionality is taken to be a prerequisite of a *generative* communication system—a property exhibited by human natural language in contrast to animal signaling systems (Hockett, 1960; Smith & Kirby, 2012). Furthermore, compositionality is often argued to be necessary for the *learnability* of such a productive communication system (Davidson, 1965; Pagin, 2012). Hence, any communication system that is capable of generating truly novel expressions that still can be processed and understood needs to be compositional (at least partly, see: Arbib, 2012). Compositionality is in this context treated as equivalent to syntactic structure and contrasted primarily with "holophrastic" (Arbib, 2012) or "holistic" languages (Smith & Kirby, 2012), where meanings can only be attributed to complete utterances. A paradigm case for holistic languages is a so-called "random" language, where there is no structure in the relations between expressions and meanings (although relations remain stable over time).

In contrast to what has been discussed in the previous section, it is the meaning of a compound expression that is assumed or bracketed, and the focus is placed on how the *structure* of the compound expression contributes to this meaning, shifting away from compositionality as specified on the level of meaning. For this reason, we will call this perspective

[2] As an important note, we do not wish to make any claims with regard to the possibility of distinguishing syntax, semantics and pragmatics, and especially semantics and pragmatics, but we will use this "levels" parlance for simplicity as it is the dominant view (see e.g., Carston, 2008).

"compositionality on the level of form."

Consider the example of a noun phrase with adjective modifier, e.g., 'red apple'. We may take the expression to refer to a particular object, or a set of particular objects, i.e., a set of red apples, and the focus is placed on how the adjective modifier ('red') in this particular structure (Adjective Noun) influences the meaning of the noun ('apple'; although there's a caveat in this example which we will explore in detail below).

The studies on the evolution of language take compositionality as an inherent property of language and focus on explaining either evolutionary pressures on the language, or formal properties required for this property to appear. For example, Lazaridou and colleagues (2018) develop simulations which flesh out the requirement of homomorphism between expressions and meanings, as they show that highly structured sensory inputs in fact support emergence of a compositional communication system. In our example above, the structure would indicate that color is a separate property from the nature of the object. Similarly, another line of research (Nowak et al., 2000; Mordatch & Abbeel, 2018) indicates that the emergence of compositionality is a solution for the communication system to deal with limitations of the size of vocabulary. In our example, this indicates the advantage of using the adjective noun structure, over inventing custom holistic names for objects that have particular properties. Earlier work has provided several simulated experiments that support the claims of the role of compositional structure for learnability (Smith & Kirby, 2012). Brighton, Smith, and Kirby (2005) show how the information transmission bottleneck (the fact that the language learner always observes only a subset of linguistic expressions) supports emergence of compositionality, and indicate in particular that this effect allows the languages to exhibit expressivity, i.e., avoid semantic ambiguity (Kirby, Cornish, & Smith, 2008). Again, in our example, this would indicate the benefit of replacing the adjective with a different one, depending on the situation, without the necessity of learning a separate structure or word. Furthermore, Kuciński and collaborators (2021) build on the suggestion of Kottur et al. (2017) that inductive biases are necessary for the emergence of compositionality and prove that in fact the presence of noise in a communication channel catalyzes the appearance of this property. In the case of the red apple, it would mean that the fact that the object named is red reduces the uncertainty of what object it can be (as only some objects are usually red), making the system more robust to noise.

Compositionality in this field remains a formally well-defined concept. This definition, as mentioned, is similar to the one provided on the level of meaning, but it centers syntax and syntactic derivations underlying compound expressions, placing limited emphasis on semantics and pragmatics, crucial for the original definition. As we will see below, this definition is also eventually used for different purposes. Recent work (see e.g., Andreas, 2019; Steinert-Threlkeld, 2020) has proposed to define compositionality as a property of a model (i.e., a communication protocol) mapping *observations* (inputs, perceived objects in the world) to *representations* ("natural language strings": words and phrases). This model is considered compositional if it is a homomorphism and each representation is determined by the structure of the set of tree-structured *derivations*, [3] which serve as labels for the input and share its structure. In the context of natural languages, these derivations are syntax trees (Andreas, 2019, p. 3). Crucially, inputs are assumed to have a compositional structure, which is then replicated by the derivations. This places derivations as reflections of the "true structure" of the world (which is assumed to be in fact compositional) and transfers this onto the representations. Korbak et al. (2020) point out also the relevant background assumption at work when one (precisely as Andreas) makes the claim that the world has a compositional structure (in the relevant sense). This requires the world to be of an analogous logical type to messages. This is precisely the issue that we pointed out in the previous section: the observations and objects in the world are transformed into logical objects, purely intellectual meanings, precluding the interactive, embodied and embedded perspective of ecological psychology and the enactive approach. At the same time, the fact that representations inherit the compositionality of derivations—of syntax, places the compositionality at a distinct level. This is why we propose here to distinguish the compositionality *on the level of form*, present in language emergence and evolution research, from the compositionality *on the level of meaning*, which is of interest to philosophy of language and linguistics, discussed in the previous section. The summary of the differences between the two "levels" is presented in table 1.

Are natural languages compositional?

Despite the huge role that the concept of compositionality has played in contemporary language research, there is no doubt that natural languages are not fully compositional, neither on the level of form, nor on the level of meaning. The dominant focus on compositionality seems to be so successful as it (in our view, correctly) recognizes the fact that language consists of compound forms made of recurring elements, and it further makes use of the common (although in our view incorrect) assumption that these elements map onto clearly defined, logically structured meanings in the form of mental representations. We do agree that natural languages contain many syntactic structures susceptible to compositional analysis, both at the level of form, and at the level of meaning (Arbib, 2012; Recanati, 2012). There are, however, plenty of examples of non-compositional—holistic or contextual—structures in languages, which go far beyond "exceptions that prove the rule", as they've been most often (dis)regarded. The most common examples are idioms and irregulars, but func-

[3] Formally, we have a set of observations $x \in X$, a model $f : X \to \Theta$, a set of derivations $\mathbf{D}$, a derivation oracle producing derivations $D : X \to \mathbf{D}$. The model f is compositional if for any x with $D(x) = \langle D(x1), D(x2) \rangle$, $f(x) = f(x1) \circ f(x2)$, where '$\circ$' is the composition operator over representations (see: Andreas, 2019; Korbak, Zubek, & Raczaszek-Leonardi, 2020).

Table 1: Summary of suggested differences between "compositionality" on different levels and in different research contexts.

Compositionality...	**on the level of meaning**	**on the level of form**
Focus	relationship between the meaning of simple and compound expressions	relationship between the structure and the meaning of a compound expression
Contrast	contextuality	holism
Research field	linguistics, philosophy of language	language evolution & emergence

tion words (determiners, auxiliaries, tenses) also pose a problem for standard approaches to compositionality. Steinert-Threlkeld (2020) proposed to account for those examples by introducing a distinction between "trivial" and "non-trivial" compositionality, with their difference consisting in the complexity of the function determining the meaning of the compound expression. In "trivially" compositional cases ("red apple", but see below) the meaning of the utterance can be determined by the intersection of the meanings of constituent expressions, i.e., "red"—the set of red objects, and "apple"—the set of all apples. In "non-trivially" compositional utterances ("biggest apple") some more complex function must be invoked to account for how constituents interact—it is impossible to identify a set of "biggest" things. Steinert-Threlkeld indicates that this is also what happens in linguistic structures, e.g., tenses, involving function words like "have" or "be."

Interestingly, as Smith and Kirby (2012) show, the most frequently used expressions of a language will have the least pressure to develop into a compositional structure. An example of this are irregular verb forms of popular verbs in English: the past tense form of "be" is in fact irregular "was", instead of the incorrect "beed", which would be a regular alternative. This indicates that compositionality helps reduce mnemonic complexity of natural languages, a fit not required in relation to popular verbs. Another important non-compositional element of language is the presence of context-dependency effects. These are far more pronounced than is usually assumed, and even in the standard example of the compositional Adjective Noun structure, mentioned previously, contextual effects are present. Compare the expression "red apple" and the expression "red brick", and consider how the word "red" shifts its meaning in those two compounds. In the result, it is difficult to find obviously trivially compositional examples in natural language, beyond the regular verb forms. These points can be taken further to claim that language "is not compositional by nature", claiming compositionality is nothing but a 'user illusion,' as some seem to claim (e.g., Steffensen & Harvey, 2018). Even if we disagree with this radical point, and the examples such as regular verbs support the claim that some linguistic structures can in fact be analyzed as compositional, this shows that compositionality cannot be treated as the sole structural property of language, and non-compositional forms are not an exception but an important rule as well.

Steffensen and Harvey (2018, p.11) indeed admit that language can in fact "be *described* as compositional if one is literate and adopts a particular theoretical perspective," although they largely reject this theoretical approach as misleading. Here we want to assume, contra Steffensen and Harvey (2018), that there is in fact a set of structural properties of language that can be usefully identified through the lens of the concept of compositionality, both on the level of meaning, and on the level of form. However, this perspective requires several significant idealizing assumptions: first, that perception of the world takes on a compositional (at least to some degree) structure, whether due to the structure of sensory inputs themselves, the world, or, possibly, due to the structure of our actions in the world. This is explicitly investigated by Lazaridou et al. (2018), but has been an implicit element of previous work on compositionality as well, as in the case of e.g., (Brighton et al., 2005), where compound meanings (observations or objects in the world) are taken to be decomposable into disentangled components (in the case of the "red apple" this means that we assume that the "redness" is in some respect detachable from the "apple-ness" of the object). Second, the requirement of a homomorphism between utterances and meanings, as indicated above, renders meanings as stable entities with a well-defined logical structure. Hence, the compositional description requires assuming that meanings are in fact static and context-free logical entities or, at the very least, that they can be meaningfully represented as such.

However, following the work in theoretical biology (Pattee, 2012b, 2012a), Raczaszek-Leonardi and Deacon (2018) consider symbolic forms to be constraints that control the dynamics of the interactions of an agent with the world and among agents. On this view, language is a highly embodied and socially embedded interactive phenomenon which escapes such clear-cut formal requirements as the prerequisites for compositionality indicated above. In fact, in previous work we have already attempted to hint at the inherent complexity of "compositionality", pointing out multiple sources of structuring necessary for it to arise (e.g., Korbak, Zubek, Kuciński, Miłoś, & Raczaszek-Leonardi, 2021). We also pointed to aspects of compositionality being important for the constraint-based approach to meaning, where the "systematicity" of linguistic forms provides both for the developmental path to the emergence of symbols (Raczaszek-Leonardi, Nomikou, Rohlfing, & Deacon, 2018) and for the presence of consistent constraints on interaction imposed by complex utterances (Raczaszek-Leonardi, 2012; Raczaszek-Leonardi, Główka, Nomikou, & Rossmanith, 2022).

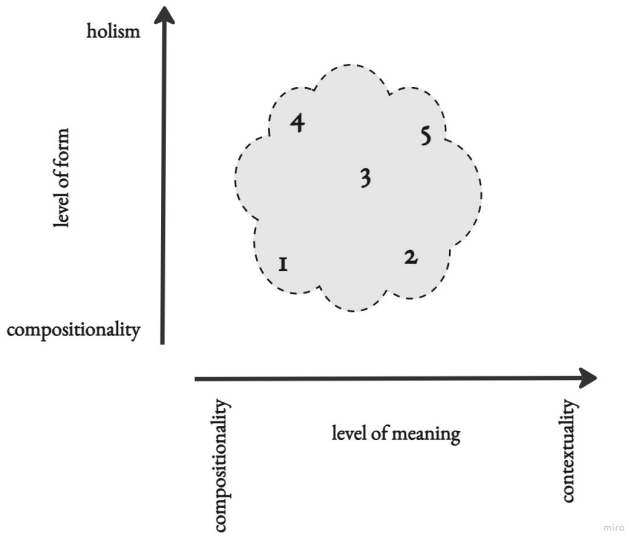

Figure 1: Visualization of the interaction and influence of compositionality, contextuality, and holism on viable states of a language, marked as the shaded region, across the levels of form and meaning. Numbers indicate plausible locations of some of the linguistic structures that we take to require the principles of compositionality, contextuality, and holism together for a full explanation: (1) regular verbs (e.g., in English Past Simple tense, with -ed), (2) non-trivially compositional structures (e.g., "red brick" vs. "red apple"), (3) structures with function words, (4) irregular verbs (e.g, in English Past Simple tense), (5) idioms.

Compositionality as an idealization

The tension between the researchers' attempt to conceive of the language as compositional through and through, the factual presence of non-compositional linguistic structures, and the idealized character of compositionality became visible in the previous section. To reconcile this tension, we propose to understand this concept as singling out one of the idealized structural properties of language, which can be used to explain the emergence of some linguistic structures, but should be considered in connection with others: most importantly, contextuality and holism.

We propose to view compositionality and contextuality, on the level of meaning, and compositionality and holism, on the level of form, as contrasting principles which can be identified in complex communication systems and that help us explain the generation of meaning of compound utterances within such systems (see fig. 1 for visualization).

To cover the structure of language more broadly, we propose to focus on the *systematicity* of natural languages, i.e., their ability to build complex expressions in a consistent and predictable way. Within systematicity, one can identify individual linguistic structures, spanning different levels of language (syntax, semantics, and pragmatics), which then can be analyzed as involving compositionality (on the level of form or of meaning), contextuality (on the level of meaning), or holism (on the level of form) to different degrees.

Each of those concepts identifies some of the constraints that are imposed on languages on different timescales. Compositionality notably allows explaining the learnability of language, the fact that it is transmissible across generations, its expressivity (as compositionally analyzable structures disambiguate polysemantic components), robustness in the presence of noise (see Kuciński et al., 2021), and last but not least, the linguistic generativity or productivity. Contextuality can be taken to account for productivity as well, as contextual effects allow the meaning of a single word to shift across different occurrences in a predictable manner—giving words flexibility (in the sense of Barwise & Perry, 1999). Holism throws light on the replicability of language and on its social roles (consider the example of idiolects and linguistic conventions, e.g., Roberts, 2013). In effect, analysis of language requires focusing on a subset of the state space defined by these contrasting principles operating on different, albeit interacting, levels (see fig. 1).

This perspective allows us to characterize some of the linguistic structures that have proven resistant to compositional analysis (see fig. 1). For example, the above-mentioned irregular verb forms, e.g., in English in the past tense, can be analyzed as showing a high level of holistic structure on the level of form, while remaining relatively compositional on the level of meaning. On the other hand, the recurring example of the subtle change of meaning of the adjective 'red' between compound expressions 'red apple' and 'red brick', may be taken to exhibit a high level of compositionality on the level of form (as an example of the Adjective Noun linguistic structure) together with contextuality on the level of meaning, as the meaning of 'red' in both expressions changes. Finally, idioms ("to kick the bucket") will exhibit a high presence of both holistic effects on the level of form, and contextual effects on the level of meaning.

Setting compositionality and its implausible assumptions aside, and focusing on contextuality and holism may open up avenues for new productive approaches to understanding meaning, even if it would be difficult to connect them with other existing—logically oriented—approaches. This is a place where our view differs significantly from that advanced by Steffensen and Harvey (2018): they recognize the false idealizations required by compositionality, and reject the concept altogether because of them. Here we believe instead that the emerging constraint- and interaction-based approach to language, developed within the framework of ecological psychology, mentioned in the previous section, may offer a way out of this dilemma, pointing to the necessity of a description of language which allows for the incorporation of all of those forms of systematicity.

This kind of pluralism is viable in the model-based view of science (consider for example the co-existence of contradictory frameworks of Newtonian and quantum mechanics

in physics; see: Cartwright, 1983; Mitchell, 2003; Wimsatt, 2007) can help us understand complex linguistic phenomena, and as such is not to be considered a stage to be overcome. This view accepts that there might not be a grand unifying theory of language, but rather that we need to concurrently develop (possibly) inconsistent and contradictory models and may—just may—eventually arrive at some real (or at the very least, useful) properties of the world in places they intersect (in the sense of Wimsatt's (2007) "robustness"). In the context of compositionality, it is important to note that this perspective allows for appreciating both the epistemic benefits bequeathed by the concept, and its highly idealized nature (most importantly, reliance on a highly improbable logic-based account of semantics). Idealizations in this philosophical approach to science are the central means for science to deal with the complexity of the world (Potochnik, 2017). As such, they introduce useful positive representations which allow science to deliver its primary goal—namely understanding (rather than truth). In effect, as Potochnik argues, idealizations are not to be expected to be removed by future developments of our scientific theories. Instead, idealizations are "rampant and unchecked" and the distortions they introduce are accounted for only by introducing alternative, possibly incongruent idealizations, and we have to be aware of both their limitations and payoffs. One way of putting this view would be to regard the concept "compositionality" (on both levels) not as a phenomenon that has to be explained (an *explanandum*), but rather just as an idealized and imperfect way of accounting for some properties of natural languages, which are better captured by notions such as "systematicity". This argument would, however, require a separate treatment, and we will set it aside for now.

Conclusions

After a brief introduction to the origins of the concept of "compositionality" we showed how various communities highlight its different aspects and contrast it with different concepts, shifting its meaning. Both on the level of form, and on the level of meaning, the concept constitutes an idealization which has been claimed to be a universal property of natural languages. However, as we argued, natural languages are in fact never fully compositional, but can nevertheless be usefully described as compositional in some areas, under particular idealizing assumptions. This led us to accepting a model-based view from philosophy of science on the role of idealizations and heuristics in science, which claims that idealizations are a necessary part of scientific inquiry. It makes sense to view compositionality as exactly that: an idealized principle of linguistic structure that needs to be complemented by other, contrasting principles: that of contextuality and of holism, as suggested here—although this list is likely not exhaustive. In fact, this proposed approach is largely coherent with the perspective that Steinert-Threlkeld (2020) proposes, showing how it can benefit researchers: his distinction of "trivial" and "non-trivial" compositionality appreciates the complex nature of systematicity in language, even if "contextuality" or "holism" are not explicitly mentioned.

To arrive at a more complete understanding of the structure of languages, researchers need to supplement the studies of the emergence of compositionality with studies which place the remaining two concepts at the fore. We hope to have made a strong argument that studies—both in the laboratory, and in computer simulation—of contextuality and holism are now highly needed. We would like to conclude by pointing out that recent developments in language emergence research may have provided just the right tools for this task.

In an important recent article, Heintz and Scott-Phillips (2022) provide a novel evolutionary perspective on the sources of the unbounded productivity of language. Elsewhere, we've argued that supplementing their account with the developmental perspective may give us a way of understanding how unbounded expression becomes constrained and structured (Rorot et al., 2022). One example is that of infants' gestures and vocalizations gaining a communicative character. In most circumstances, all the children has to do is utter a particular sound for the caretakers to fulfill their need. This initial utterance (or gesture), although simple, already exhibits structural properties (Raczaszek-Leonardi et al., 2018). This expression is perhaps best considered as a kind of "action at a distance." The child's expression constrains actions of the caretaker who will then aim to fulfill the needs of the child, and meet shared values of interacting agents in the situation (i.e., the survival and well-being of the child). This contextual, situated and interactive character of language, already present at its beginning, does not disappear when forms of expression more susceptible to logical analysis become available to the growing person. Hence, this simple case of children's initial gestures and utterances offers a fertile ground for studies of both compositional and non-compositional elements of linguistic structure.

We believe that the approach proposed here will highlight the relevant timescales on which the researchers should focus while searching and modeling various sources of structure in language, eventually allowing us to understand the systematicity of language in all its complexity.

Acknowledgments

The authors would like to thank the members of the Human Interactivity and Language Lab for insightful comments on the earlier version of the paper. An early version of this work has been presented at the 10th Peripatetic Conference on Cognitive Systems Modeling, organized by University of Warsaw, in Zakopane, Poland, October 2021. The work on this paper has been funded by the OPUS grant 2018/29/B/HS1/00884 from National Science Center, Poland awarded to JRL. WR's contribution was enabled by the funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 952324.

References

Andreas, J. (2019, April). Measuring Compositionality in Representation Learning. *arXiv:1902.07181 [cs, stat]*.

Arbib, M. A. (2012, February). Compositionality and Beyond: Embodied Meaning in Language and Protolanguage. In W. Hinzen, E. Machery, & M. Werning (Eds.), *Oxford Handbook of Compositionality* (pp. 475–492). Oxford University Press. doi: 10.1093/oxfordhb/9780199541072.013.0024

Barwise, J., & Perry, J. (1999). *Situations and attitudes*. Stanford, Calif: CSLI Publications.

Brighton, H., Smith, K., & Kirby, S. (2005, September). Language as an evolutionary system. *Physics of Life Reviews*, *2*(3), 177–226. doi: 10.1016/j.plrev.2005.06.001

Carston, R. (2008, December). Linguistic communication and the semantics/pragmatics distinction. *Synthese*, *165*(3), 321–345. doi: 10.1007/s11229-007-9191-8

Cartwright, N. (1983). *How the Laws of Physics Lie*. Oxford University Press. doi: 10.1093/0198247044.001.0001

Davidson, D. (1965). Theories of meaning and learnable languages. In Y. Bar-Hillel (Ed.), *Proceedings of the International Congress for Logic, Methodology, and Philosophy of Science* (pp. 3–17). North-Holland.

Di Paolo, E. A., Cuffari, E. C., & De Jaegher, H. (2018). *Linguistic Bodies: The Continuity between Life and Language*. The MIT Press. doi: 10.7551/mitpress/11244.001.0001

Frege, G. (1960). *The Foundations of Arithmetic* (J. Austin, Trans.). New York: Harper & Brothers.

Heintz, C., & Scott-Phillips, T. (2022, January). Expression unleashed: The evolutionary & cognitive foundations of human communication. *Behavioral and Brain Sciences*, 1–46. doi: 10.1017/S0140525X22000012

Hockett, C. F. (1960). The origin of speech. *Scientific American*, *203*(3), 88–97.

Horwich, P. (1997, October). The Composition of Meanings. *The Philosophical Review*, *106*(4), 503. doi: 10.2307/2998510

Janssen, T. M. (2012). Compositionality: Its Historic Context. In M. Werning, W. Hinzen, & E. Machery (Eds.), *The Oxford handbook of compositionality.* Oxford ; New York, NY: Oxford University Press.

Kirby, S., Cornish, H., & Smith, K. (2008, August). Cumulative cultural evolution in the laboratory: An experimental approach to the origins of structure in human language. *Proceedings of the National Academy of Sciences*, *105*(31), 10681–10686. doi: 10.1073/pnas.0707835105

Korbak, T., Zubek, J., Kuciński, Ł., Miłoś, P., & Raczaszek-Leonardi, J. (2021, December). Interaction history as a source of compositionality in emergent communication. *Interaction Studies. Social Behaviour and Communication in Biological and Artificial Systems*, *22*(2), 212–243. doi: 10.1075/is.21020.kor

Korbak, T., Zubek, J., & Raczaszek-Leonardi, J. (2020, October). Measuring non-trivial compositionality in emergent communication. *arXiv:2010.15058 [cs]*.

Kottur, S., Moura, J. M. F., Lee, S., & Batra, D. (2017, August). Natural Language Does Not Emerge 'Naturally' in Multi-Agent Dialog. *arXiv:1706.08502 [cs]*.

Kracht, M. (2012). Compositionality in Montague Grammar. In M. Werning, W. Hinzen, & E. Machery (Eds.), *The Oxford handbook of compositionality.* Oxford ; New York, NY: Oxford University Press.

Kuciński, Ł., Korbak, T., Kołodziej, P., & Miłoś, P. (2021, November). Catalytic Role Of Noise And Necessity Of Inductive Biases In The Emergence Of Compositional Communication. *arXiv:2111.06464 [cs]*.

Lazaridou, A., Hermann, K. M., Tuyls, K., & Clark, S. (2018, April). Emergence of Linguistic Communication from Referential Games with Symbolic and Pixel Input. *arXiv:1804.03984 [cs]*.

Mitchell, S. D. (2003). *Biological complexity and integrative pluralism*. Cambridge, UK ; New York, N.Y: Cambridge University Press.

Montague, R. (1970, December). Universal grammar. *Theoria*, *36*(3), 373–398. doi: 10.1111/j.1755-2567.1970.tb00434.x

Mordatch, I., & Abbeel, P. (2018). Emergence of grounded compositional language in multi-agent populations. In *Proceedings of the thirty-second AAAI conference on artificial intelligence and thirtieth innovative applications of artificial intelligence conference and eighth AAAI symposium on educational advances in artificial intelligence.* New Orleans, Louisiana, USA: AAAI Press.

Nowak, M. A., Plotkin, J. B., & Jansen, V. A. A. (2000, March). The evolution of syntactic communication. *Nature*, *404*(6777), 495–498. doi: 10.1038/35006635

Pagin, P. (2012, February). Communication and the Complexity of Semantics. In W. Hinzen, E. Machery, & M. Werning (Eds.), *Oxford Handbook of Compositionality* (pp. 510–529). Oxford University Press. doi: 10.1093/oxfordhb/9780199541072.013.0024

Partee, B. H. (2004). *Compositionality in formal semantics: Selected papers of Barbara H. Partee*. Malden, MA: Blackwell Pub.

Pattee, H. H. (2012a). Cell Psychology: An Evolutionary Approach to the Symbol-Matter Problem. In *LAWS, LANGUAGE and LIFE* (Vol. 7, pp. 165–179). Dordrecht: Springer Netherlands. doi: 10.1007/978-94-007-5161-$3_1$1

Pattee, H. H. (2012b). How Does a Molecule Become a Message? In *LAWS, LANGUAGE and LIFE* (Vol. 7, pp. 55–67). Dordrecht: Springer Netherlands. doi: 10.1007/978-94-007-5161-3_3

Potochnik, A. (2017). *Idealization and the aims of science*. Chicago: The University of Chicago Press.

Raczaszek-Leonardi, J. (2012). Language as a System of Replicable Constraints. In *LAWS, LANGUAGE and LIFE* (Vol. 7, pp. 295–333). Dordrecht: Springer Netherlands. doi: 10.1007/978-94-007-5161-$3_1$9

Raczaszek-Leonardi, J., & Deacon, T. W. (2018, September). Ungrounding symbols in language development: Implica-

tions for modeling emergent symbolic communication in artificial systems. In *2018 Joint IEEE 8th International Conference on Development and Learning and Epigenetic Robotics (ICDL-EpiRob)* (pp. 232–237). Tokyo, Japan: IEEE. doi: 10.1109/DEVLRN.2018.8761016

Raczaszek-Leonardi, J., Główka, K., Nomikou, I., & Rossmanith, N. (2022, September). Time-to-smile, time-to-speak, time-to-resolve: Timescales for shaping engagement in language. *Language Sciences*, *93*, 101495. doi: 10.1016/j.langsci.2022.101495

Raczaszek-Leonardi, J., & Kelso, S. J. (2008, August). Reconciling symbolic and dynamic aspects of language: Toward a dynamic psycholinguistics. *New Ideas in Psychology*, *26*(2), 193–207. doi: 10.1016/j.newideapsych.2007.07.003

Raczaszek-Leonardi, J., Nomikou, I., Rohlfing, K. J., & Deacon, T. W. (2018, January). Language Development From an Ecological Perspective: Ecologically Valid Ways to Abstract Symbols. *Ecological Psychology*, *30*(1), 39–73. doi: 10.1080/10407413.2017.1410387

Recanati, F. (2012, February). Compositionality, Flexibility, and Context Dependence. In W. Hinzen, E. Machery, & M. Werning (Eds.), *Oxford Handbook of Compositionality* (pp. 475–492). Oxford University Press. doi: 10.1093/oxfordhb/9780199541072.013.0024

Roberts, G. (2013, December). Perspectives on Language as a Source of Social Markers: Perspectives on Linguistic Social Markers. *Language and Linguistics Compass*, *7*(12), 619–632. doi: 10.1111/lnc3.12052

Rorot, W., Skowrońska, K., Nagórska, E., Zielinski, K., Zubek, J., & Raczaszek-Leonardi, J. (2022, April). *Structuring unleashed expression: Developmental foundations of human communication* (Preprint). PsyArXiv. doi: 10.31234/osf.io/tyva9

Smith, K., & Kirby, S. (2012, February). Compositionality and Linguistic Evolution. In W. Hinzen, E. Machery, & M. Werning (Eds.), *Oxford Handbook of Compositionality* (pp. 493–509). Oxford University Press. doi: 10.1093/oxfordhb/9780199541072.013.0024

Steffensen, S. V., & Harvey, M. I. (2018, May). Ecological meaning, linguistic meaning, and interactivity. *Cognitive Semiotics*, *11*(1), 20180005. doi: 10.1515/cogsem-2018-0005

Steinert-Threlkeld, S. (2020, December). Toward the Emergence of Nontrivial Compositionality. *Philosophy of Science*, *87*(5), 897–909. doi: 10.1086/710628

Szabó, Z. G. (2012, February). The Case for Compositionality. In W. Hinzen, E. Machery, & M. Werning (Eds.), *Oxford Handbook of Compositionality* (pp. 64–80). Oxford University Press. doi: 10.1093/oxfordhb/9780199541072.013.0024

Szabó, Z. G. (2020). Compositionality. In E. N. Zalta (Ed.), *The Stanford encyclopedia of philosophy* (Fall 2020 ed.). Metaphysics Research Lab, Stanford University.

Thompson, E. (2010). *Mind in life: Biology, phenomenology, and the sciences of mind* (1. Harvard Univ. Press paperback ed ed.). Cambridge, Mass.: Belknap Press of Harvard Univ. Press.

Werning, M., Hinzen, W., & Machery, E. (Eds.). (2012). *The Oxford handbook of compositionality*. Oxford ; New York, NY: Oxford University Press.

Wimsatt, W. C. (2007). *Re-engineering philosophy for limited beings: Piecewise approximations to reality*. Cambridge, Mass: Harvard University Press.