Algebraic Structures in Natural Language

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Grammar through Spontaneous Order

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ABSTRACT

How do the algebraic regularities in natural language, described by generative grammar, emerge? One traditional viewpoint has been that these are encoded with a species-specific and innately specified universal grammar, which has somehow come to be part of the human biological endowment. From this point of view, the strange mix of regularities, subregularities, and downright exceptions observed across languages and levels in linguistic analysis are somewhat puzzling. An alternative perspective is that language begins through attempts to solve immediate communicative problems between specific people on specific occasions; but each new communicative exchange draws on precedents from past exchanges, and sets precedents for future exchanges. Over time, specific linguistic patterns will become entrenched, and layered upon each other, to create a complex spontaneously ordered system, analogous to case law. From this point of view, the algebraic patterns in language are always various, partial and subject to exceptions.

3.1 INTRODUCTION

Language, like so much else in the natural and cultural worlds, is a curious mix of order and disorder. Where does this order come from? And why is it mixed with

disorder – with collisions between rules and downright exceptions? In this chapter, we will argue that the answers to these questions may be related.[1]

In explaining any mixture of order and disorder, we can take either one or the other as basic. First, let us consider what we shall call the "order-first" viewpoint. According to this view, there are some underlying forces which initially create the orderly pattern in its "pure" form. For example, we might suppose that there is a purely logical "language of thought" built into the mind of each person (where the order of this logical language comes from, we will not enquire). This language of thought, having the form of something like predicate calculus or a more expressive logical language has an orderly, and in particular algebraic, structure. It has a well-defined set of syntactic rules (generating the familiar syntactic tree-structures or some equivalent), and a compositional semantics defined over those rules. But this orderly structure is then assumed to be disturbed by other more unruly forces, for example, concerning the practical challenges of communication. For example, it may be assumed, we somehow have to encode these purely logical structures into a convenient form that can be spoken or signed; and this must be done in the light of a myriad of practical constraints. Shortcuts and ad hoc devices may be useful to get particular messages across rapidly; cognitive limitations might have distorting impacts on how we convey ideas that have excessive logical complexity; ambiguities might be allowed, and even functionally appropriate, where context is sufficient to make it "obvious" what is meant and time is short (Piantadosi, Tily, & Gibson, 2012). More broadly, from this general standpoint, the mixture of orderly and disorderly aspects of languages arises from the multitude of "corrupting" influences of practical constraints on what is, at base, a perfectly orderly system.

This "order-first" picture can, of course, be filled out in a variety of ways. For example, Chomsky has proposed that sentences have a syntactic representation, LF, over which semantic interpretation is defined.[2] Chomsky's LF is not quite a conventional logical language, though it does have a "pure" algebraic structure and compositional semantics (Chomsky, 1995). According to the minimalist program, patterns in language then arise through the process of optimising the relationship between LF and phonological representations (or, more generally, optimising the mapping between conceptual representations and the sensorimotor system). This optimisation is not, perhaps surprisingly, presumed to be based on practical considerations, such as statistical regularities in what messages need to be conveyed, fine-details of the operation of the auditory system, the speech apparatus, or memory, but is viewed in much more abstract terms. Nonetheless, some of the irregularities and complexities of natural language, at least, can be seen as arising from the inherently messy task of mapping from LF to a sound-based representation.[3] Indeed, the minimalist program

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[1] The ideas in this chapter are outlined more extensively in Christiansen and Chater (2022).

[2] In particular, LF is designed to resolve scope ambiguities: For example, the different meanings of *every book published in English are stored in a well-known library* – where this sentence might be taken to imply that there is a single such library (so that a natural question would be which one?), or only to say that every book is stored in some well-known or other (so that no library need be completely comprehensive). The relationship between LF and related ideas in linguistics and the traditional concept of logical form in the philosophy of language is debated (e.g., Stich, 1975).

[3] If language is primarily for thought, rather than communication, then the process of translating

proposes that many aspects of language can be explained on the assumption that this mapping will generate inevitable complexity – even if the mapping is as "perfect" as possible (Chomsky, 1995; Lasnik, 2002). Many of the quirks of individual languages are, though, viewed as relegated to the "periphery" rather than the "core" of language, and are viewed as being of rather little linguistic interest.[4] Another popular, although by no means essential, aspect of this type of view is that the most essential elements of the algebraic structure of language, captured in a so-called "universal grammar," arise not purely from domain-general principles of cognition but from a genetically encoded language faculty (e.g., Chomsky 1980). Thus, the orderly nature of language arises, this point of view, from a language faculty – a genetically specified, and language-specific set of biological constraints.[5] Quite what constraints the language faculty is presumed to contain is not at all clear, but it is generally assumed at least to include recursion, which may seem particularly central to the algebraic structure of language.

Other very different approaches to generative grammar and compositional semantics may have different theoretical presuppositions. But the order-first story is usually tacitly assumed across many areas of linguistics and the philosophy of language. Indeed, the order-first viewpoint is built into approaches to languages which assume that sentences have an underlying logical form (whether that logical form is cognitively represented or not), a viewpoint which can be traced back to the inception of analytic philosophy with the work of Frege (see Dummett, 1981) and Russell (1905). Similarly, to the degree that the compositional semantics of natural language is presumed to be patterned on the compositional semantics of formal logical languages, the "order-first" viewpoint is built into the view of language emerging from Tarski's theory of truth and Montague Semantics (e.g., Dowty, Wall, & Peters, 1981).

We have so far reviewed the idea that language is at root orderly, but made disorderly by contact with extra-linguistic factors of various kinds. But our objective in this chapter is to explore the opposite perspective. From this point of view, language

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from LF to a phonological form seems to be entirely pointless. Indeed, it seems to be counterproductive, because surely reasoning is defined over logical, not phonological, representations. Moreover, if language were centrally involved in thought, then intelligent thought should be largely eliminated in global aphasics (with no language) and should show distinctive neural traces of covert natural language processing. Neither prediction appears to be correct (Fedorenko & Varley, 2016). Now, of course, it may be that the process of generating natural language helps us clarify and formulate our thoughts. Of course, one might wonder whether it is possible even to make sense of the very idea of thoughts, independent of their expression in a publicly accessible language, in the light, for example, of Wittgenstein's and Kripke's thoughts on rules and private languages (Kripke, 1982). But this would be to suggest that the process of communication is essential to thought, and hence language is useful for thinking not independently of its communicative function, but because of its communicative function.

[4]Chomsky is loath to see interesting aspects of language as arising from practical considerations of communication, in the light of his counterintuitive view that language is primarily for thought rather than communication mentioned above. (For opposite viewpoints, see, e.g., Christiansen & Chater, 2016; Gibson et al., 2019; Hahn, Jurafsky & Futrell, 2020; Hawkins, 1994).

[5]We have argued elsewhere that telling an evolutionarily credible story about the origin of such a language faculty is very difficult (Christiansen & Chater, 2008). Whether recursion is either language-specific rather than a general property of human cognition is also very much to open to challenge (e.g., Christiansen & Chater, 2015; Conway & Christiansen, 2001).

should be viewed as by the default ad hoc and disorderly; but order emerges, to an extent, through the pressures on different linguistic forms generated by their endless use and reuse, and crucially the interactions between them. That is, the patterns in language arise through a process of *spontaneous order*.

3.2   SPONTANEOUS ORDER: THE VERY IDEA

The idea of spontaneous order in social phenomena is imported, originally, from the natural sciences.[6] Polanyi (1941), a leading physical chemist early in his career, noted that coherence in the domains of ideas, culture, and social structure might potentially arise through the process of mutual balancing and interaction of forces analogous to that observed when ice forms intricate snowflakes, gas coheres in into spherical bubbles in a liquid, or water 'finds a level' a container. He initially termed this mutual balancing of the interactions between many independent elements with no central coordination 'dynamic order' later shifting to 'spontaneous order' (Polanyi, 1951). Polanyi viewed the processes by which the mind organises sensory input as operating according to such principles, attributing this viewpoint to the Gestalt psychologist Wolfgang Kohler (1929/1970). Moreover, he viewed science as having the same character being, in a sense, an extension of perception. In both domains, local scraps of information and insight are continually in tension – some mutually reinforcing each other, and others in competition. This process of alliance and jostling leads, from the bottom up, to a more or less coherent representation of the patterns in the external world.

In practice, the huge variety of representations created by the perceptual system are not fully coherent (Dennett, 1993; Svarverud, Gilson, & Glennerster, 2012). Similarly, our representations of the common-sense physical properties of the everyday world, our moral judgements, or our mathematical intuitions are inevitably partial and inconsistent. As far as possible, perceptual processing (or scientific theorising) attempts to piece together locally coherent models of aspects of reality (e.g., Kelso, 1995; Kugler & Turvey,1987; Thelen & Smith, 1996), but our understanding is full of gaps and contradictions (Chater, 2018; Chater & Oaksford, 2017; Rozenblit & Keil, 2002). Indeed, it has been argued that, even in physics, we have no more than a patchwork of loosely connected local models of different phenomena, which cannot be joined up to form a consistent global representation of the world (Cartwright, 1983, 1999). Still, the attempt to bring local insights into alignment where possible is the route by which our models and theories become increasingly, though inevitably partially, coherent.

The idea of spontaneous order has particularly been taken up in economics (Hayek, 1960; Krugman, 1996; Sugden, 1989), to help understand how the tenuous and largely myopic interactions of makers, buyers, and sellers in a hugely complex web somehow conspire to generate and produce goods and services, supply chains, and financial and legal machinery of a complexity far beyond the understanding of

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[6]In the natural sciences, spontaneous order is usually known as self-organisation (e.g., Camazine, Deneubourg, Franks, Sneyd, Theraula & Bonabeau, 2001; Nicolis & Prigogine, 1977).

any individual market participant. But Polanyi (1941) intended the idea much more generally, to apply to culture broadly defined, including natural language:

> The social legacies of language, writing, literature and of the various arts, pictorial and musical; of practical crafts, including medicine, agriculture, manufacture and the technique of communications; of sets of conventional units and measures, and of customs of intercourse; of religious, social and political thought all these are systems of dynamic order which were developed by the method of direct individual adjustment, (Polanyi, 1941, p. 438)

And Hayek sees language as a particularly striking example on spontaneous order. As Schmidtz and Boettke (2021) explain, Hayek argued that:

> Just as no one had to invent natural selection, no one had to invent the process by which natural languages evolve. A language is a massively path-dependent process of unending mutual adjustment. Language evolves spontaneously. It would make no sense to call any language optimally efficient, but it does make sense to see languages as highly refined and effective adaptations to the evolving communication needs of particular populations. (Hayek. 1945, p. 528).

So much for the big picture. But how might a story of the spontaneous evolution of language work? And how might it explain the algebraic-style regularities that appear so prominent in language? How, indeed, can it explain the mixture of order and disorder that seems so typical across every aspect of language, from phonology to syntax and semantics?

3.3   FROM CHARADES TO GRAMMATICALISATION

In the party game of charades, people attempt to communicate through novel gestures, with the use of language being expressly forbidden. Inevitably, much of the work is done by iconicity – people attempt to mime particular actions, form shapes suggesting a particular object or mimic an individual person's characteristic gestures and movements. But as the game progresses, particular gestures can rapidly become conventionalised – a full scale re-enactment of a golf shot (initially part of a mime to indicate Tiger Woods) may become a little more than a swish of the forefinger. It may, moreover, be reused, perhaps with additional gestures, when attempting to convey the game of golf, the US Masters or even an actual tiger (see Christiansen and Chater, 2022, for extensive discussion of the charades metaphor for linguistic communication).

There is no algebraic structure here, of course. Instead, all the work is being done by loose and creative invention, and, crucially, the repurposing and gradual conventionalisation of previously used charades. But as each new charade is interpreted in the light of previous charades, we might expect that increasing standardisation of

gestures and their deployment will arise. But where does the algebraic structure of grammar come from?

A natural answer is through processes of grammaticalisation identified in the study of language change. Grammaticalisation is "the development from lexical to grammatical forms and from grammatical to even more grammatical forms" (Heine and Kuteva, 2002, p. 377). It provides a mechanism from which a simple charade-like communication can be gradually transformed into a much more complex and systematic linguistic system. Heine and Kuteva (2007) attempt to reconstruct the broad patterns of such changes by looking at the historical language record – but they propose that the same general patterns of change will have operated long before writing systems were invented, and may run back to the very origin of language. From this perspective, language evolution is language change "writ large," rather than involving the biological evolution of a language faculty, or indeed, language-specific cognitive machinery of any kind, as assumed in many accounts of language evolution (e.g., Pinker & Bloom, 1990).

Grammaticalisation provides a mechanism for local changes to the language – but of course to create a linguistic system, requires the interaction, and mutual constraint, of many such changes. To generate spontaneous order, rather than merely independent threads of linguistic change, requires that an aspect of the language is under pressure to adjust to fit in with its neighbours. And such pressures are not only present but are many and varied. The fundamentally case-based and analogical nature of learning and memory will continually impose generalisation: gently tending to pull similar linguistic items to behave still more similarly. To take the simplest possible case, if the linguistic contexts in which *dog* and *cat* are used heavily overlap, it is likely that generalisation will tend to increase their overlap still further. Thus, while each lexical item might, initially, have distinct distributional behaviour, the distributions of similar items will tend to become more similar still, so that lexical items can, increasingly, be grouped by their distributional properties. In short, such a process will gradually group words into increasingly discrete syntactic categories. But the inherently partial and unsystematic nature of such generalisation does not guarantee the emergence of a small finite set of syntactic categories used by traditional grammarians, or in generative grammar. Instead, we should expect the processes of spontaneous order to be no more than partial. Indeed, Culicover (1999) persuasively argues that the distributional properties of words do not break neatly into distinct categories. To slightly adapt one of Culicover's examples (1999, p 47), we might imagine that *likely* and *probable* must have the same syntactic (and indeed semantic) properties. But there remain curious cases where the two do not have the parallel distributional properites, even though there is no difficulty semantically interpreting the anomalous sentence (1d):

(1) a. It is likely that John will be elected President next year

    b. It is probable that John will be elected President next year

    c. John is likely to be elected President next year

    d. *John is probable to be elected President next year

Culicover shows convincingly that these types of cases are ubiquitous throughout language – so much so, indeed, that he argues that it may be appropriate to see each individual word as having its own unique distributional characteristics and hence, in a sense, its own unique syntactic category. The forces of spontaneous order will, though, continually operate to bring innumerable conflicting local patterns into a more orderly form, while innovation to solve ever-changing communicative challenges will continually inject more variety, and hence disorder.

While a thorough-going construction-based perspective on language, such as Culicover's, sees abstract syntactic categories as abstractions from the diverse idiosyncratic behaviours of individual words, these abstractions nonetheless provide a useful when considering the process through which function words and morphological markers arise through the cultural evolution of language. It is easy enough to imagine how communication can be kick-started with, perhaps initially iconic, sounds or gestures to denote specific objects or actions. But it is less clear how markers for tense and aspects, case markings, determiners, conjunctions, and the like might form through processes of spontaneous change.

According to a grammaticalisation account, the puzzle is solved by observing that entrenchment and increasing conventionalisation can lead words in one syntactic category to shift into another – a process which typically flows only in one direction. A sketch of some of the key pathways is outlined in Figure 3.1 (based on Heine and Kutova, 2007), based on historically recorded language change (possibly only, of course, for written languages) and inevitably more speculative language reconstruction where there is no written record.

Languages can, of course, evolve in a wide variety of ways. From the perspective of spontaneous order, this is just what we should expect. Of course, there will be many overlapping patterns arising from any process of biological or cultural evolution, both through shared evolutionary history and process of coevolution. But there should be no "archetypal" languages or underlying "bauplan" for all languages, any more than there is an archetypal snow-flake. Indeed, the process of diversity ramifying in many and varied directions is the normal outcome in process of cultural and biological evolution alike. Religious traditions, agricultural technologies and institutions for managing common resources (e.g., Ostrom, 1990) are all remarkably diverse, and the spectacular variety of the biological world exemplifies the non-existence of any single optimal self-reproducing creature to which all life-forms are converging.

If an underlying bauplan for all languages could be uncovered, this would be strong evidence for the order-first viewpoint and against the spontaneous order perspective advocated here. The existence of such a bauplan is, we suggest, better viewed as a methodological assumption in the Chomskian tradition than an established fact. Indeed, exploration of the phonological, syntactic, and semantic properties of the world's languages seems continually to throw up astonishing variety, rather than revealing common underlying patterns (Evans & Levinson, 2007).
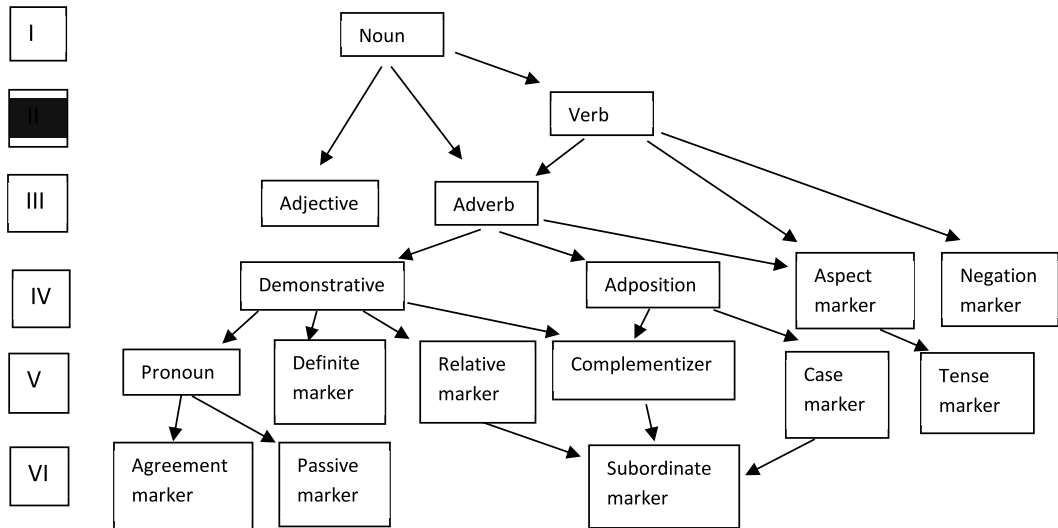
Figure 3.1   A reconstruction of historical transitions in syntactic categories through grammaticalisation (redrawn from Heine, Kaltenböck, & Kuteva, 2013).

3.4   THE EMERGENCE OF HIERARCHICAL STRUCTURE AND COMPOSITIONALITY

One of the most powerful communicative pressures on language is, of course, the ability to efficiently express a wide variety of meanings. In a game of charades, we may initially sequence our gestures in a rather haphazard way. But processes of grammaticalisation may naturally entrench particular orders as having particular semantic interpretation, so that word order may become increasingly stable. Indeed, this is also observed in the improvised gestural communicative systems sometimes created by deaf children and hearing parents. Such so-called "home sign" systems typically develop regularities in word order, usually adopted more thoroughly by child learners than their parents (Goldin-Meadow & Mylander, 1998).

Moreover, we should also expect the hierarchical structure of meaning to induce a degree of hierarchical structure at the level of syntax. So, for example, to pick out one object, we may need first to pick out another, so that noun phrases must be able be embedded within each other. Thus, it hard to imagine a useful language without at least a minimal hierarchical structure (e.g., [*the woman* [*with* [*a hat*]]]). And then we should expect that, by default at least, these larger units will operate syntactically roughly in the same way as phrases that pick out the same object directly (e.g., *Gladys*) – because we want to say the same types of things about people, however we pick them out (e.g., [*the woman with a hat*]/[*Gladys*] *likes singing*; *does* [*the woman in a hat*]/[*Gladys*] *like singing*?; and so on). More generally, we might reasonably expect something close to a phrase structure grammar spontaneously to emerge purely from these simple constraints.[7] Indeed, on the face of it, the ability of

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[7]A hierarchical "chunked" structure to language may also be required where no compositional semantics is involved – purely to deal with the severe processing bottleneck in both production

small communities rapidly to create rich structured communicative systems over a few generations testifies that this is possible (as in the well-known cases of Nicaraguan sign language Kegl, Senghas, & Coppola, 1999).[8]

Compositionality also helps with learnability, of course. The simpler the mapping between meanings and linguistic forms, the more briefly that mapping can be encoded and the less linguistic input should be required to learn it (Hsu, Chater, & Vitányi, 2011). Compositional mappings are, of course, particularly simple. Moreover, a wide range of laboratory studies on the cultural evolution of artificial languages (e.g., Beckner, Pierrehumbert, & Hay 2017; Kirby, Cornish, & Smith 2008; Kirby, Tamariz, Cornish, & Smith 2015) have shown that sequential, meaningful units can spontaneously emerge from meaningless elementary units (e.g., morphs arise from the concatenation of phones), without explicit supervision or teaching, from a process of iterated learning (the input for each learner is the output of a previous learner). Recently, it has been shown that sensitivity to word order, and hierarchical structures can rapidly and spontaneously be generated in laboratory conditions (Saldana, Kirby, Truswell, & Smith, 2019).

But there will, of course, be many additional pressures on the cultural evolution of language, which will complicate this picture considerably. In broad terms, to modify Givón's well-known adage,[9] yesterday's pragmatics is today's syntax. Thus, the pragmatic drive to communicate briefly may lead to omissions and compressions of syntactic patterns. This line of thinking was developed by the philosopher and logician Hilary Putnam in an early critique of the nativist program in linguistics (Putnam, 1967). He points out that a standard phrase structure grammar for an artificial logical language would generate a structure with the form "That is $\exists!x(x$ is a lady and I saw you with x last night)"[10] which may be contracted to *That is the lady I saw you with last night* (traditionally explained in terms of a transformation, leaving a "gap" between *with* and *last*). Of course, the rules governing which such "abbreviations" are grammatically acceptable are subtle – but it seems entirely possible that these constraints may arise from ease-of-processing, rather than innately specified constraints on the structure of language itself.

In a rather different vein, Levinson (1987, 2000) argues persuasively that pragmatic factors may explain the origin of many interesting aspects of grammar, including the binding constraints (Chomsky, 1981). For example, standard pragmatic

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and comprehension (Christiansen & Chater, 2016) – as is observed in the hierarchically chunking in music (Lerdahl & Jackendoff, 1983), in mnemonic strategies for recalling long sequences of digits (Ericsson, Chase, & Faloon, 1980), an in the hierarchical structure of actions and plans more broadly (Dezfouli, Lingawi, & Balleine, 2014).

[8]The rapid emergence of complex linguistic structure in Nicaraguan sign language is often taken as evidence for the innateness of such structure. We suggest the opposite: that it indicates how processes of spontaneous order can arise rapidly in the absence of language-specific constraints through the necessity to communicate. Of course, as with any aspect of cultural evolution, the outcome will depend on the cognitive machinery of the agents involved, but we see no compelling reason to believe that this machinery is language-specific.

[9]The original aphorism is: "today's morphology is yesterday's syntax," Givón, T. (1971, p.413).

[10]Here we use $\exists!x$ to denote "there exists a unique, such that. . . " rather than the less usual notation in Putnam's original quotation.

principles imply that the availability of the word *himself* leads to the presumption that in *John likes him* the pronoun *him* does not refer to John – otherwise the more precise *himself* would have been used. This type of pragmatic reasoning is very general and is, indeed, observed in communicative exchanges with entirely arbitrary non-linguistic signals (e.g., Misyak, Noguchi, & Chater, 2016). But when, through normal processes of grammaticalisation, this assumption of non-coreference becomes increasingly obligatory, it becomes more naturally viewed a part of syntax rather than pragmatics (although, according to the present perspective, the boundary between the two is graded, rather than all-or-nothing). Levinson develops similar arguments to create a comprehensive account of the origins of Chomsky's (1981) binding constraints, and putative exceptions to them, purely using pragmatic principles. Thus, syntactic phenomena that may seem highly abstract and arbitrary may be explicable through processes of spontaneous order, deriving from the gradual interaction, and conventionalisation, of regularities with pragmatic origins.

With any such explanations it is, of course, always possible to argue about the details – indeed, such argument is quite rightly the very essence of linguistic debate. But the existence of such historical explanations, even where partial and incomplete, strongly suggests that many apparently abstract principles of grammar result from processes of spontaneous order. At least if we presume the opposite, that they are arbitrary constraints built into a language-specific universal grammar (taking the standard order-first viewpoint), then the possibility of finding potential historical lines of explanation for such phenomena using pragmatic principles appears to be a remarkable and unexplained coincidence.

3.5   IS THE ALGEBRAIC STRUCTURE OF LANGUAGE MENTALLY REPRESENTED?

Nature is full of patterns. But typically, these patterns arise from complex sets of rules which are represented only in the mind (and by the mathematical tools) of the theorist. Thus, the elliptical orbits of the planets emerge from the "laws" of gravitation. But the planets are not, of course, representing those laws – or indeed, representing anything at all. The planets are *governed* by these rules but do not *follow* them – in the sense of consulting and conforming to a representation of those rules.

In the natural sciences, the spontaneous emergence of complexity always has this character: snowflakes form complex geometric patterns with rich symmetries but do not in any way represent those patterns (there is, of course, no blueprint that the freezing water molecules need consult to ensure that a snowflake grows appropriately). Similarly, the astonishing complexity of a wasp nest or an ant colony is not represented in the mind (or the genes) of any individual wasp or ant; rather, this complexity emerges, somehow, through the playing out of the presumably fairly simple local rules that govern the laying down and following of pheromone trails and the like.

According to advocates of spontaneous order in the social sciences, the story is the same for human culture. The remarkably complex structures in human societies,

patterns of economic interaction, financial markets, and cultural products of all kinds, are not represented, and do not need to be represented, by the agents whose busy interactions somehow collectively create them. Indeed, the process of social scientific explanation seems naturally to fit with this perspective. Social scientists are typically trying to provide "rational reconstructions" (to borrow, and somewhat repurpose, a suggestive phrase of Lakatos [1970]) that explain why social and culture systems operate successfully. Thus, for example, theorists wonder about the underlying rationale that allows fiat money (not based on some good of intrinsic value such as gold) to serve as a reliable story of value and medium of exchange; what kind of logic underpins the value of intangible assets of a company, such as reputation, or what determines the allocation of capital to investment projects, the divergent structures of companies in different industries, or the allocation of rewards to workers with different skills (e.g., Cabral, 2017); or even, extending this style of explanation further and perhaps more controversially, the economic logic behind dowries, bride-prices, patterns of inheritance, even the nature and functioning of the family unit (e.g., Becker, 1991). Or consider the linguistic turn that has been distinctive of twentieth century philosophy. Here, a common view of the project of philosophy is to attempt to create a set of rational principles that can explain our diverse and apparently rather contradictory intuitions about causality, mind, morality or any other topic. But in none of these domains is there typically an assumption that the "true" theory is mentally represented in the minds of the people engaging in economic transactions, social interactions, or ethical thought. Indeed, from the spontaneous order viewpoint, this is as it should be: complex order arises from networks of the interactions of large numbers of units or agents and will not be represented in any individual unit.

Language seems to be an archetypical collective cultural construction, generated by the layering of countless conversational interactions, each focussed only on the communicative demands of the moment but gradually stretching and pulling the language in new directions. Curiously, though, an influential strand of linguistics in the order-first tradition we described above has adopted precisely the opposite perspective. Chomsky (1980) explicitly argues that language (or at least a somewhat idealised form of language as actually spoken) is fundamentally a property of each individual human; that the "interesting" structure of the language (the universal grammar) is represented in the mind of each individual; and, moreover, that these representations are innately specified in the genes, and ultimately the brain, of each child. From this perspective, the algebraic structure of language is built in.

There are many difficulties with this order-first nativist perspective on the algebraic structure of language, which we will not review here (e.g., Chater, Clark, Goldsmith, & Perfors, 2015; Clark & Lappin, 2010; Culicover, 1999; Evans & Levinson, 2009; Pullum & Scholz, 2002; Putnam, 1967; Tomasello, 1992). Here, we have primarily aimed to present and illustrate the viability of the opposite viewpoint, drawing especially on the theory of grammaticalisation. Moreover, drawing parallels with complex phenomena across the natural and social sciences, we have illustrated the possibility of rich algebraic patterns arising in language through a process of

spontaneous order.[11] Thus, we hope to persuade the reader that the idea that patterns arise spontaneously from complex patterns of interactions between many agents over countless generations, while the agents do not in any way mentally represent those patterns, is plausible in the case of language.

Indeed, we hope the spontaneous order viewpoint can help shift researchers away from what has often been an order-first, nativist explanation as the default assumption in some areas of the science of language. The patterns observed in language are endlessly subtle and puzzling. But the right starting point from which to address such puzzles is, we believe, through exploring the variety of interacting forces operating on the development of language. Natural languages are shaped by the specifics of perception, motor control, memory, learning, pragmatic factors, and the relentless forces of grammaticalisation. There is both the relentless language-internal jostling to reconcile local, partially inconsistent constraints and the need for generalisation to deal with new communicative challenges. These processes have, over time, generated a continual flow of new linguistic innovation and a gradually and spontaneously emerging order, generating the vast range of regularities, sub-regularities, and outright exceptions that are characteristic of natural language (Christiansen & Chater, 2022).

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[11]Indeed, we could equally have considered the algebraic patterns, often modelled by rather sophisticated group theory, that arise in the patterns in the visuals arts (Weyl, 1952) and in music (Benson, 2006).

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