Communicative & Integrative Biology 4:5, 516-520; September/October 2011; ©2011 Landes Bioscience

Can mathematics explain the evolution of human language?

Guenther Witzany
Telos-Philosophische Praxis; Bürmoos, Austria

Investigation into the sequence structure of the genetic code by means of an informatic approach is a real success story. The features of human language are also the object of investigation within the realm of formal language theories. They focus on the common rules of a universal grammar that lies behind all languages and determine generation of syntactic structures. This universal grammar is a depiction of material reality, i.e., the hidden logical order of things and its relations determined by natural laws. Therefore mathematics is viewed not only as an appropriate tool to investigate human language and genetic code structures through computer science-based formal language theory but is itself a depiction of material reality. This confusion between language as a scientific tool to describe observations/experiences within cognitive constructed models and formal language as a direct depiction of material reality occurs not only in current approaches but was the central focus of the philosophy of science debate in the twentieth century, with rather unexpected results. This article recalls these results and their implications for more recent mathematical approaches that also attempt to explain the evolution of human language.

Key words: formal language, linguistic turn, incompleteness theorem, pragmatic turn, speech acts, biocommunication, natural genome editing

Submitted: 05/26/11

Accepted: 05/27/11

DOI: 10.4161/cib.4.5.16426

Correspondence to: Guenther Witzany;
Email: witzany@sbg.at

Introduction

In a series of articles Martin Novak tries to apply formal language theory to explain the evolution of human language. He suggests that the evolution of syntax (grammar) occurs as a simplified rule system that itself evolved by natural selection.[1,2] Identification of meaning (semantics) occurs through identification of correct syntax. Human language evolved by representing the "grammar of the real world that is, the underlying logic of how objects relate to actions and other objects."[1]

Following Noam Chomsky Nowak proposes a universal grammar that represents the inner logic of nature. This inner logic of nature forms neuronal networks of brain architecture. Because this architecture depicts the inner logic of nature it functions according to natural laws which can be analysed by formalisable procedures such as mathematics. Universal Grammar specifies the mechanism of language acquisition also: "Universal Grammar is not learned but is required for language learning. It is innate."[3]

Because language has evolved to reduce communication mistakes "only a universal grammar satisfies the coherence threshold that can promote the evolution of grammatical communication."[3] Alongside the 3 billion-year-old generative system of the nucleotid language human language emerged as a comparable generative system.[4]

Nowak is convinced that fundamental aspects of human language are amenable to formal analysis. In his approach mathematics and computer science-based formal language theory function as appropriate mathematical machinery to deal with these phenomena to investigate and analyse language-specific rules that generate meaningful linguistic structures.[4] In this respect, languages, grammar and machines have some correspondence: context-free languages are generated by context-free grammars, which can be implemented by push-down automata. Context sensitive languages are generated by context sensitive grammars. For each of these languages there exists a Turing machine, which can decide whether it is a regular language or not.[4]

In a more recent work in reference 5, Nowak tries to undertake a complete mathematical theory of social evolutionary dynamics of humans by assuming that an "evolving population consists of reproducing individuals, which are information carriers. When they reproduce they pass on information. New mutants arise if this process involves mistakes."[5] Information is inherited by replication. Errors (mutation) in replication lead to variation. Selection leads to survival of the fittest variants.[6]

The ambitious claim that his mathematical approach is not simply a language-based scientific concept but a depiction of biological reality[5] raises the question of how to justify scientific sentences and of the role of language in general. This was the central question in the philosophy of science debate in the twentieth century, with rather unexpected results.

The Linguistic Turn in the 1930s

One of the key events in the science history of the 20th century was the debate on how to establish an exact scientific language. Increasing empirical data had to be interpreted correctly to adapt knowledge to technical applications. The previous 2,000 years were dominated by a variety of philosophical conceptions that could not solve basic problems of empirical investigations and construction of theories.

Modern empiricism wanted to be free of metaphysical implications.[7] Therefore the only serious value as far as science was concerned was the rationality of methods for reaching scientific knowledge, i.e., the formalisable expression of empirical sentences.[8] This was called objectivism, and it restricts itself to a pure observer perspective that confirms its observations by measurement techniques and subsumes reality in the formalisable depiction of these measurements. Between metaphysics and objectivism there is an unbridgeable gap: only what can be found empirically and described as formalisable exists.

This scientific approach represented a fundamental shift in the history of rational thinking. It focused not on things, the world, processes and their relations but conversely the medium in which we describe our observations, experiences, concepts.[9] The important starting-point at this stage was that everything we see as part of material reality follows a natural logic of relations according to natural laws. If we want to describe material reality, then we have to investigate and describe objects in the realm of physics and chemistry, which are the only appropriate tools. The only language which is able to describe these objects and their relations is mathematics.[10] Every sentence with which observations are described as well as sentences which are used to construct theories must fulfil the criterion of formalisabilty.[11] Sentences which are not formalisable can be excluded from science. Natural laws expressed within the language of mathematics represent the inherent logic of nature.[12] The central and most important element of language is therefore syntax. Only through syntax does the logical structure of a language as a depiction of the logical structure of nature reveal itself.[13]

Similarly to this model of language, systems theory and information theory investigate the empirical significance of scientific sentences by means of a quantifiable set of signs and, additionally, the information transfer of formalised references between a sender and a receiver. Information processing systems are therefore quantifiable themselves. Understanding information is possible because of the logical structure of the universal syntax, i.e., by a process which reverses the construction of meaning. Therefore information theory is also a mathematical theory of language.[14,15] Both constructions are able to depict reality by means of formalized sentences like a picture or a photo in contrast to sentences which describe within the realm of a theoretical model. Manfred Eigen took this formal language theory to describe the genetic code as a regular language.[16]

Manfred Eigen Adopted this Position Early

Thirty years before Martin Nowak's work Manfred Eigen explicitly compared human language with molecular genetic language. Both serve as communication mechanisms. The molecular constitution of genes is possible, according to Eigen, because nucleic acids are arranged according to the molecular syntax of this language. Through this comparison Manfred Eigen follows the depiction theory of language within the tradition of mathematical language theory, systems theory and information theory. The world behaves according to physically determinable natural laws. These natural laws can be expressed only by using the language of mathematics. The essential rules of a language are therefore its syntax.[16]

The semantic aspect of language initially comprises an incidentally developed or combined sign sequence, a mixture of characters, which only gains significance in the course of specific selection processes. The linguistic signs are variables whose syntax is subject to the natural laws governing the neuronal architecture of the sign-using brain organ. The brain of humans is endowed with these variables and combines them to reflect synapse network logics. The variable sign syntax of the brain must then be filled with experiences of a personal nature and thus constitutes an individualized evaluation scheme. In messages between communication partners, one side encodes the message in phonetic characters. The receiver must then decode and interpret the message according to empathy and personal experience. Understanding messages shared between sender and receiver is possible largely because the uniform logical form—a universal grammar—lies hidden behind every language.[16]

Gödel's Incompleteness Theorem: Functions Lacking Algorithms are Not Calculable

A similar situation (but more than 40 years before Eigen) is encountered in the attempt to absolutise mathematics as a purely formal language. This led Gödel to formulate the *Unvollständigkeitssatz* (incompleteness theorem) in his work *Über formal unentscheidbare Sätze der principia mathematica und verwandter Systeme.*[17]

Gödel's aim was to convert metatheoretical statements into arithmetical statements by means of a specific allocation procedure. More precisely, he strove to convert the statements formulated in a meta-language into the object language S by using the object language S. This led Gödel to two rather unexpected but far-reaching conclusions: (1) on the assumption that system S is consistent, then it will contain one formally indeterminable theorem, i.e., one theorem is inevitably present that can be neither proved nor disproved within the system, (2) on the assumption that system S is consistent, then this consistency of S cannot be proved within S.

The question of determinability and calculability is closely allied with the algorithm concept, whereby Eigen postulated that algorithms are not only concepts of theoretical language, but also depict (decision-) behavior in the realm of biology and, therefore, are amenable to formal analysis. He was convinced that everything can be represented in the form of algorithms and can thus, in principle (after sufficiently thorough analysis), be determined. This, however, neglects the consequence of the incompleteness theorem for that of the automaton theory of Turing and Neumann: a machine can principally calculate only those functions for which an algorithm can be provided. Functions lacking an algorithm are not calculable.

Both Manfred Eigen and Martin Nowak assumed that the evolution of self-reproducing and self-organizing organisms represents the realisation of the universal grammar underlying the logical order of the world. This universal grammar, as a representation of mathematically expressible reality, is also the formal basis for the evolution of these organisms.

The Pragmatic Turn: Children Learn Non-Formal Languages in Interactions

In his later work[18] Wittgenstein refuted his early concept completely by abandoning the ideal of a world-depicting universal grammar. In contrast to former concepts which thought that behind any language lay a material reality which determined the visible order of languages (universal grammar) Wittgenstein proved that this is not the case. The most essential background of language is its concrete use by consortial interacting humans. The meaning of a word is its use (Wittgenstein 1953). The real use of a language in its everyday context is always the unity of language embedded in actions. This designates what was later termed "pragmatic turn" in contrast to the former "linguistic turn." Whereas in linguistic turn thinking the formal order in the syntax (universal grammar) played an essential role, now it was the context of consortial interacting humans in real life that played a crucial rule in the emergence of meaning in speech acts and utterances.

This unity of language and actions Wittgenstein called *Sprachspiel* (language game). Game, because as in every game so also in language there are certain valid rules. It is not possible to choose any kind of language to take a position behind the practice of a lifeform by means of basic reasoning. Language itself is the last bastion as the real practice of actions and is primarily a social phenomenon. Wittgenstein worked out why it is impossible to construct a private (solus ipse) language. In his analysis of the expression "to obey a rule," Wittgenstein provides proof that the identity of meanings logically depends on the ability to follow intersubjectively valid rules with at least one additional subject; there can be no identical meanings for the lone subject. Speaking is a form of social action. Meaning is a social function.[19] The rules of language games have developed historically as "customs" from consortial real-life usage. To understand the rules one must co-play within such a game. Then one can see the meaning of a term because as co-player one gains experience of how a term is used within this play, which rules determine its meaning and how the rules may change according to varying situations.

Children do not learn language, words or sentences by means of innate universal grammar in that they reduce mistakes in understanding but look at interactional motifs of parents and others combined with words.[19-22] Within social interactions they learn "how to do things with words" or how to combine words with actional motifs.[22] Speaking, making propositions and understanding utterances do not operate by means of a private encoding process, and subsequently a private decoding process, but by means of consortially shared rule-governed sign-mediated interactions. The shared competence to follow semiotic rules and the socialised linguistic competence to build correct sentences enable interaction partners to understand identical meanings of utterances.[19,22]

Non-Formal Everyday Language as Ultimate Meta-Language

The fact that paradoxes arising within a formal language cannot be solved with that language led to a differentiation between object-language and meta-language. Nonetheless, paradoxes can also appear within meta-language;[23] these can only be solved by being split into meta-language, meta-meta-language and so forth in an infinite number of steps. This unavoidable gradation of meta-languages necessitates resorting to informal speech, developed in the context of social experience, as the ultimate meta-language. Informal language is the last instance for deciding on the paradoxes emerging from object- and meta-languages. The only way to decide whether a mathematical formula is true or false is by using a non-formal language.[17] One cannot decide this from the formal language itself. With non-formal languages one can easily change from formal to non-formal and vice versa.[19,22] Interestingly this is completely impossible for formal language.

This non-formal language is the tool that enables the language itself to be discussed.[19,22] A computer is unable to do this because no algorithm is available with which a cybernetic machine can determine its underlying formal system.

Scientists Learn Formal Languages in Scientific Communities

When the pragmatic turn replaced the linguistic turn this was because from now on it was not the syntax and semantics that were the central focus of investigation of languages but (1) the subjects which interact with languages as well as (2) the pragmatic aspects in which these interacting subjects are interwoven and which determine how an interactional situation is able to be constituted as such.[19] The complementarity and non-reductionability of the three levels of rules (syntax, pragmatics, semantics) which are at the basis of any natural language used in communicative actions were commonsense elements.[24]

Language therefore is not solely the subject of scientific investigation of a technique for information storage or transport but depends primarily on language-using consortia (language-game communities) of subjects with linguistic and communicative competences in real social contexts of a real lifeworld.[19-22] On the other hand, it is not possible to develop an exact language of science which functions like the logical order of material reality because scientific languages are also spoken by real-life subjects and the validity claim of objectivism to eliminate all inexact parameters of subjects does not function even in the scientific language game.

Also, scientific languages depend on utterances which are preliminary; they are as open as any real-life language and therefore can generate real novelties, new sentences which did not exist before, and therefore are able to progress in knowledge.[25] Because utterances in scientific languages are subject to debate by scientific communities and are constantly under pressure to justify themselves they may contribute "in the long run" (Charles Sanders Peirce) to progress in knowledge.[19]

Locutionary and Illocutionary Speech Acts

Because subjects share linguistic and communicative competences, i.e., can generate correct sentences and instal reciprocal interactions, they are able to differentiate rule-based as well as rule-contradictory linguistic behaviors. They are able to express a variety of meanings with identical syntactic structures. An utterance like, for instance, "the shooting of the hunters," can therefore transport rather different meanings which are clearly context-dependent.

This led John Austin in his legendary speech-act theory[20,21] to the differentiation of locutionary and illocutionary speech acts. He made the assumption that besides the superficial (locutionary) grammatical structure of a verbal utterance human interactors may perform certain actions (performative acts) with an utterance that is not explicit (illocutionary) in the grammatical structure. Illocutive aspects can therefore hardly be explained by syntactic analysis of grammatical structures. In this respect syntactic analyses cannot extract context-dependent meaning, because meaning is not a quality of syntactic structures but of context-dependent social interactions. This fundamentally contradicts computer science-based formal language theory and makes sense in terms of saving energy cost as well: not for every meaningful content is it necessary to generate a unique grammatical structure (sentence).

Consequences for Formal Language Theories

Natural language has proved to be a perpetually open system that cannot guarantee definitiveness from within itself.[17,23] The consequences of this debate in the twentieth century for the use of mathematics in investigating natural languages/codes are rather surprising:

• There can be no formal system which is entirely reflectable in all its aspects while at the same time being its own metasystem.

• Concrete communicative acts are basically unlimited in their possibilities. There will always be lines of argumentation that lie outside and have no connection with an existing system. Every system can be transcended argumentatively in principle. Newly-emerging language games and rules may develop as novel structures which are foreign to previous systems and not merely a further step in a series of prevailing elements. Therefore completely new grammatical coherent sequences are not the result of errors or misperceptions.

• The ultimate meta-language, informal language, provides indispensable evidence about the communication practice of consortial subjects in the real environment; operators of formalisations are themselves an integral part of this. Reverting to this everyday type of communication reveals information about the subjects practising this usage.

• In natural languages syntactic, pragmatic and semantic rules must be identifiable. If one level of rules is missing, one cannot speak about a natural language seriously.

• In natural languages pragmatics (context) determines meaning (semantics) of syntactic sequences, not the inherent logic of grammar.

Biocommunication and Natural Genome Editing

Communication in general can be both empirically investigated and understood as rule-governed sign-mediated interaction.[26] This is essentially different from chemical-physical interactions in inanimate nature, because the latter are not governed by semiotic rules. The complementarity of combinatorial (syntactic), context-dependent (pragmatic) and content-sensitive (semantic) rules is lacking if water freezes to ice. In contrast to this the presence of these rules that mediate every sign use—whether it be indices, icons or symbols—is equally valid for human communication and communication in non-human life.[27]

From this perspective we can identify several code-based communicative competences in non-human animate nature that underlie syntactic, pragmatic and semantic rules. Investigations in, e.g., bacteria,[28,29] animals,[30,31] fungi[32,33] and plants[34,35] palpably demonstrate that practically all organisms coordinate by code-based communication processes. More specifically, no coordination between cells, tissues, organs and organisms can be described appropriately without communication processes. If communication functions properly these processes will be coordinated in an optimised (selective) manner; if they are deformed, coordination will have deficits or fails.

Interestingly, more and more empirical data suggest that the genetic code functions according to the rules of natural languages. This means that investigations of the genetic code must be able to identify competent agents that generate nucleotid sequences de novo, integrate them into host genomes and regulate them according to the cellular needs of host organisms[36] and their capability of natural genetic engineering.[37] The insertion or deletion of whole genes and gene sets (up to 100 complete genes within one infection event) by viruses, apparently plays a more important evolutionary role in genetic change than single chance mutations (errors) can achieve.[38] Think of the remnants of such infection events as still active as regulatory consortia that act with cut-and-paste (transposons) as well as copy-and-paste (retrotransposons) competences to recode and recombine genetic content orders and their rich regulatory elements.[39-42]

Conclusion

Besides genetic code and human language we are currently able to identify a variety of natural languages that are used in all kingdoms by organisms to coordinate consortial interactions within and between cells, tissues, organs and organisms. Biocommunication designates that semiochemicals in signaling codes in bacteria, plants, animals and fungi are structured by syntactic, pragmatic and semantic rules that are absent in inanimate nature. Natural genome editing transposes random changes of genetic content order by errors (mutation) through competent consortia of agents that edit natural languages/codes, e.g., generate nucleotid sequences de novo, integrate, regulate and—if adaptionally necessary—delete genetic content accordingly. This perspective seems to be more coherent with current knowledge about the role of epigenetic modifications, non-coding RNAs, early RNA-world hypothesis, RNA-editing, mobile genetic elements and the role of viruses in the evolution of all life than error-based (mutation) changes of genetic content and their selection as the dominant resource of genetic innovation as suggested by the formal language theory of mathematics.

References

1. Nowak MA, Krakauer DC. The evolution of language. Proc Nat Acad Sci USA 1999; 96:8023-33.
2. Nowak MA, Plotkin JB, Jansen VAA. The evolution of syntactic communication. Nature 2000; 404:495-8.
3. Nowak MA, Komarova NL, Niyogi P. Evolution of universal grammar. Science 2001; 291:114-8.
4. Nowak MA, Komarova NL, Niyogi P. Computational and evolutionary aspects of language. Nature 2002; 417:611-7.
5. Nowak MA, Tarnita CE, Antal T. Evolutionary dynamics in structured populations. Philos T Roy Soc B 2010; 365:19-30.
6. Manapat ML, Chen IA, Nowak MA. The basic reproductive ratio of life. J Theor Biol 2010; 263:317-27.
7. Carnap R. Überwindung der Metaphysik durch logische Analyse der Sprache. Erkenntnis 1931; 2:219-41.
8. Carnap R. Die physikalische Sprache als Universalsprache der Wissenschaft. Erkenntnis 1931; 2:432-65.
9. Wittgenstein L. Tractatus logico-philosophicus. London: Kegan Paul, Trench 1922.
10. Russel B. An inquiry into Meaning and Truth. London: George Allen & Unwin 1941.
11. Carnap R. Logische Syntax der Sprache. Wien: Springer 1934.
12. Carnap R. Foundations of Logic and Mathematics. Chicago: University of Chicago Press 1939.
13. Carnap R. Der logische Aufbau der Welt. Berlin: Weltkreis-Verlag 1928.
14. Shannon CE, Weaver W. The Mathematical Theory of Communication. Urbana: The University of Illinois Press 1949.
15. Turing A. Computing Machinery and Intelligence. Mind, New Series 1951; 59:433-60.
16. Eigen M, Winkler R. Das Spiel. Naturgesetze steuern den Zufall. München: Pieper 1975.
17. Gödel K. Über formal unentscheidbare Sätze der principia mathematica und verwandter systeme. Monatsh Math Phys 1931; 38:173-98.
18. Wittgenstein L. Philosophical Investigations. Oxford, UK: Basil Blackwell 1953.
19. Apel KO. Towards a Transformation of Philosophy. Boston: Routledge and Kegan Paul 1980.
20. Austin J. How to Do Things with Words. Oxford: Clarendon Press 1962.
21. Searle JR. Speech acts. Cambridge, UK: Cambridge University Press 1969.
22. Habermas J. The Theory of Communicative Action. Boston: Beacon Press 1984.
23. Tarski A. Einführung in die mathematische Logik. Goettingen: Vandenhoeck & Ruprecht 1966.
24. Morris CW. Signs, Language and Behavior. New York: G. Braziller 1946.
25. Kuhn TS. The Structure of Scientific Revolutions. Chicago: University of Chicago Press 1962.
26. Witzany G. From the "logic of the molecular syntax" to molecular pragmatism. Explanatory deficits in Manfred Eigen's concept of language and communication. Evol Cog 1995; 1:148-68.
27. Witzany G. Biocommunication and Natural Genome Editing. Dordrecht: Springer 2010.
28. Bassler BL, Losick R. Bacterially Speaking. Cell 2006; 125:237-46.
29. Ben Jacob E, Becker I, Shapira Y. Levine H. Bacterial linguistic communication and social intelligence. Trends Microbiol 2004; 12:366-72.
30. Frisch Karl v. Bees: Their Vision, Chemical Senses and Language. Ithaca: Cornell University Press 1971.
31. Lindauer M. Communication among social bees. Cambridge, MA: Harvard University Press 1971.
32. Lengeler KB, Davidson RC, D'Souza C, Harashima T, Shen WC, Wang P, et al. Signal transduction cascades regulating fungal development and virulence. Microbiol Mol Biol Rev 2000; 64:746-85.
33. Witzany G. Uniform categorization of biocommunication in bacteria, fungi and plants. World J Biol Chem 2010; 1:160-80.
34. Baluska F, Manuso S, Volkmann D, eds. Communication in Plants. Heidelberg/Berlin: Springer 2006.
35. Baluska F, Mancuso S, eds. Signaling in Plants. Heidelberg/Berlin: Springer 2009.
36. Witzany G, (Ed.). Natural Genetic Engineering and Natural Genome Editing. New York: Wiley & Blackwell 2010.
37. Shapiro JA. A 21st century view of evolution: genome system architecture, repetitive DNA and natural genetic engineering. Gene 2004; 345:91-100.
38. Villarreal LP. Viruses and the Evolution of Life. Washington: American Society for Microbiology Press 2005.
39. Brosius J. The contribution of RNAs and retroposition to evolutionary novelties. Genetics 2003; 118:99-115.
40. Frost LS, Leplae R, Summers AO, Toussaint A. Mobile genetic elements: the agents of open source evolution. Nat Rev Microbiol 2005; 3:722-32.
41. Sternberg R, Shapiro JA. How repeated retroelements format genome function. Cytogenet Genom Res 2005; 110:108-16.
42. Slotkin RK, Martienssen R. Transposable elements and the epigenetic regulation of the genome. Nat Rev Genet 2007; 8:272-85.