An Evolutionary Cybernetics Perspective on Language and Coordination

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1 Introduction and Problem Setting

1.1 Language and Language Evolution

Understanding language and its evolution is arguably one of the hardest open problems of contemporary science. The study of language has traditionally been divided into sub-fields such as syntax, semantics or pragmatics. Especially in the last century, the question of what the subject of syntax is, has received a clear and unambiguous answer: it is anything that can be captured by a Turing machine, that is, anything that involves the algorithmic, rule based manipulation of symbols.

Accordingly, one of the main strategies pursued in linguistics has been to postulate the existence of an idealized, static and abstract set of categories and rules. Shannon's theory of communication [Shannon, 1948], Chomsky's "universal grammar" [Chomsky, 1955] and De Saussure's "langue" [de Saussure, 1974] are well known examples of such syntactic theories of language and communication.

It is now clear that the complexity of language resides not just in the fact that it is a highly complex combinatorial symbol system, but also in that it cuts through every level of cognition [Fillmore, 1985, Langacker, 1987, Tomasello, 1995, Kay and Fillmore, 1999, Bergen and Chang, 2005, Croft, 2007]. Furthermore, language is a social, distributed phenomenon, making it a "moving" target that involves several levels of organization and complexity [Steels, 2000, Croft, 2005, The Five Graces Group, 2008, Thibault, 2011, Cowley, 2011]. These are not issues of syntax, but of semantics, and answering them requires to take a *dynamic* stance instead of a static one. To put it bluntly, there is no "langue" or "universal grammar", these are Platonic idealizations, epi-phenomena that cannot be the starting point nor the primary target of explanation. Instead, we might seek an understanding of the mechanisms and processes that may *lead* to something like language, and in this way explain its primary characteristics as a symbolic system: that it is arbitrary, that it is conventional (distributed and shared), and that it allows increased coordination among language users into higher levels of organization.

To be clear, this is not to say that "traditional" approaches have no value. Language technologies will always require knowledge of the intricacies and wonders of natural languages. Linguistics, particularly functional and cognitive linguistics, provides many insights into the formal structure (the "syntax") of the semantics involved in human languages. Although these approaches have lead to tremendous progress, they also have their limitations and leave open a number of pertinent questions, such as what it is that makes information meaningful, or syntax useful – in other words, questions regarding the fundamental *nature* of semantics.

At one level, what we are arguing for in this paper is the following. First, that "traditional" enquiries into language take a number of assumptions for granted that nevertheless require further explanation, a fact that might be hindering further progress in several respects. Examples of such assumptions are the static or Platonic nature of conceptual categories and the idea that problems of semantics or "qualification" are essentially reducible to problems of syntax.

Second, that such assumptions should be addressed in a fundamental manner from the bottom up. For instance, it is the "exploitability" of observed structure in the interaction with the world that "grants" such structures their quality as categories, which in turn gives them their symbolic or syntactic status. We therefore argue that we must focus our attention on building a theory of "qualification" or semiosis.

Third, we acknowledge that the issue of semantics is only part of the problem of language. As mentioned, another part is its collective and emergent nature, which is directly related to the problem of linguistic coordination – the primary topic of this issue. Nevertheless, we argue that a thorough account of the problem of coordination also requires a semantic foundation. On top of that, it requires an evolutionary perspective.

Finally, we argue that the issues raised are not just what currently hinders progress in linguistics, but in many other branches of science, particularly Cognitive Science [Chemero, 2009] and Biology [Deacon, 2006, Kalevi et al., 2009]. They are related to the issue of reductionism versus holism, of matter versus mind, of nature versus nurture. They embody the tension between dualism and naturalism, which has been part of science at least since Plato, was recognized at least since Descartes, and requires resolution in order to proceed.

It is of course one thing to point towards a number of open issues and another to propose solutions. We do not claim to have a solution for all issues raised. As mentioned, at one level the contribution of this paper is to set the stage and point towards that we think deserves more attention. This will be the topic of this introductory part, where we discuss in more detail some of the issues we think lie at the heart of the problem of semantics. It concerns the notions of "categories", "arbitrariness" and "semiosis".

In the second part we then approach these issues more rigorously from the viewpoint of cybernetics, and discuss why we think that a dynamical systems approach makes a very good starting point for further enquiry.

The third part builds further on this by introducing evolutionary theory, where we want to contribute to the further development of an evolutionary cybernetics account of language and coordination in a fundamental manner [Heylighen et al., 1991, Turchin, 1977]. Although such an organization of the paper implies a long "introduction" before we get to the main topic of the current issue – coordination – we feel that such a foundational treatment has a lot to say about the nature of the phenomenon we are dealing with, and how we should go about tackling them.

For obvious reasons, the general character of all issues raised cannot be covered in full detail, but the broad range of topics and fields the paper reaches out to may serve as an illustration. At the same, we apologize if this may have lead us to sometimes only give an incomplete or not entirely correct account.

1.2 Issues of Semantics

1.2.1 Categories and Symbols

We begin our listing of open issues with that of "categories" (or "qualia" or "particulars" [Bickhard, 2011]), because it is fundamental in several respects. In our opinion, one thing that needs critical revision is the nature of so called "semantic categories", for instance in formal and computational theories of language [Sag et al., 2003, Bergen and Chang, 2005, Steels and De Beule, 2006]. Often cited examples of such categories include "agent", "patient", "animate" etc. They are contrasted to "syntactic categories" such as "subject" or "noun", which are fully arbitrary and do not carry any intrinsic meaning, hence "syntactic". As part of a formal grammar or theory of language, however, it is often unclear what the intrinsic difference between both types of categories is. This is because the fundamental distinction between semantics and syntax does not lie in how certain symbols are named, not even in terms of the role they play in some rule based production system or grammar. The distinction lies in how "categories" and "symbols" can be defined and identified in the first place, that is, without postulating their existence beforehand.

From a static, Platonic perspective, 'noun' and 'adjective' are universal categories. But none of them exist but as part of (models of) the way we conceptualize our primary and most abstract means of communication, namely language. Such categories are language specific [Croft, 2005, Evans and Levinson, 2009, Levinson and Evans, 2010, Haspelmath, 2010], and the same holds for "semantic" categories like 'agent', and even of other categories that are not exclusively associated with language, like perceptual categories. These may be more constrained by the specific physiological pre-wiring of our sense organs and brain etc., but that does not make them any less "arbitrary" or "syntactic", not from the broader perspective of macro-evolution or physics [Bridgman, 1959, Martin and Gordon, 2001]. As another example, consider that it is fundamentally not possible to devise a "universal speech recognizer" that automagically learns the boundaries between "words" from nothing but a stream of sounds. It might be possible to discover phonemes or other formal regularities by which the stream of sounds can be described more concisely, as in algorithmic complexity theory, but not meaningful units or "words", simply because the length of words is completely arbitrary. For all the system may know, an entire stream of arbitrary length might be considered a single "word". The same is true for any stream of inputs: as long as there is no way to qualify structures that can be discovered in them, nothing can ever receive any meaning and as such be granted the status of a "symbolic unit" or "useful category". The question regarding the nature of semantic and syntactic categories is thus misleading, and the question concerning the nature of categories in general is ill-posed, because it requires reference to a qualification process and thus a qualifying entity.

At the moment, the incorporation of "semantics" into theories of language often boils down to adding another layer of syntax, e.g. a "semantic pole" or slot in a formal feature structure. Even when the semantics are claimed to be grounded through "situated embodiment" in robotic experiments, a closer analysis often reveals that the real semantics reside in pre-programmed ways to find referents in the world through pre-calibrated image processing techniques, or in pre-set interaction scripts.[1] The situation does not appear all that different from the one described by Drew McDermott in a 1976 paper titled "artificial intelligence meets natural stupidity" [McDermott, 1976]: just because we *call* something "semantic", "joint attention" or "turn-taking" does not mean that anything of the kind is actually going on. Of course, tremendous progress was made since McDermott, and we do not wish to downgrade the often truly impressive advances made. In fact, we have been part of it ourselves (although only in modest ways, see e.g. [Wellens and De Beule, 2010, Micelli et al., 2009, De Beule and Steels, 2005]). It is precisely for this reason that we feel we can more clearly point towards open issues that hinder further progress at a fundamental level, because at the least they are hindering us.

1.2.2 Arbitrariness and Agency

Another issue of semantics already hinted at briefly in the previous section is that of *arbitrariness*. It was mentioned that the boundaries of words in a language are arbitrary in the sense that they are not an intrinsic property of a stream of sounds or letters. But arbitrariness is also what characterizes words at another level: they can be put in arbitrary relationships to other things. As such words, like symbols, "stand for" something. And since different words may stand for similar meanings in different languages, the relation between words and their meaning is arbitrary.

Arbitrariness is not just confined to language, it is one of the main characteristics of all of human culture. But it even occurs outside of human culture. Even the genetic code is arbitrary. As it turns out, many arbitrary codes can be found in nature [Barbieri, 2008b]), end they all seem to have appeared during so called metasystem or major transitions towards increased levels of coordination [Szathmáry and Maynard-Smith, 1995, Barbieri, 2008c]. We might thus gain some understanding about the character of symbols and coding from investigating the concept of "arbitrariness" more closely.

[1] For some notable exceptions to this general trend, see [Quinn, 2001, Nolfi et al., 2008, Tuci et al., 2010].

The first thing to note is that even though a relation may be arbitrary, it still is a relation. Thus, there is a definite relationship between a word and its meaning in a particular language at a particular time. This is readily checked by using an imperative, such as "stop!", and observe the effect. That the relation is arbitrary just means that the cause-effect relation it embodies could have been different and is not reducible to the "laws of nature" or, more precisely, of physics. This in turn means that there must be entities at work that actively explore possible new cause-effect relationships and maintain or *realize* them. We might call such entities "agencies".

1.2.3 Qualification or Semiosis

Now if we say that the issue of categories is ill-posed, how do we want to account for them? The answer is that they are the result of processes of exploration and maintenance by agencies. Thus, categories are not intrinsic properties of things, they are imposed upon things by an agency that "qualifies" them as meaningful categorizations of the world in relation to themselves, that is in relation to the agent's "purposes", and in result realizes and maintains them. But what does it mean to "qualify"? In other words, what characteristic properties must systems posses before they can be considered "agencies"? This arguably is the single most important outstanding question in contemporary science. It not only lays at the heart of semantics, and therefore of language, but even of life itself [Anderson et al., 1984, Barbieri, 1985, Rosen, 1991, Sebeok and Umiker-Sebeok, 1992, Hoffmeyer, 1996, Sebeok, 2001, Barbieri, 2008a, Kalevi et al., 2009].

The process of "qualification" is also known as "signification" or "sense-making" or "semiosis".[2] According to Peircean semiotics, a characteristic property of semiosis is *self-referentiality* which, as we will argue, may well be the defining property of agency we are looking for. As Gödel, Church and Turing already showed, self-referentialities or *impredicatives* may lead to infinite regresses and thus go beyond the realm of syntax [Rosen, 1991, De Beule, 2012c]. We claim that the problem of self-referentiality lays at the heart of semantics, and therefore begs for a resolution. We will now set out to tackle it using the toolkit of Cybernetics.

2 Steps Towards a Theory of Semantics

2.1 Cybernetics

There are several reasons why cybernetics is appropriate to investigate issues of semantics and language. Perhaps the most obvious is its relation to information theory or, as Shannon called it, the "theory of communication". Information theory, in many respects, can be seen as part of cybernetics [Ashby, 1956]. In order to show how information theory is related to the issues of semantics, we go back to the "engineering problem" Shannon was considering when he wrote his classic paper [Shannon, 1948]:

> "The fundamental problem of communication is that of reproducing at one point either exactly or approximately a message selected at another point. Frequently the messages have meaning; that is they refer to or are correlated according to some system with certain physical or conceptual entities. These semantic aspects of communication are irrelevant to the engineering problem. The significant aspect is that the actual message is one *selected from a set* of possible messages."

Two interesting observations can be made in this quotation with respect to the current discussion. First, that Shannon apparently thought that semantics can be reduced to how certain symbolic messages are connected to some other type of particulars. As mentioned, we think that this misses the point, or at least is misleading. The second observation is that a fundamental ingredient of information theory is that sender and receiver can agree upon a set of possible messages or categories *beforehand*, that is, before communication in the Shannon sense can take place. But agreeing upon something already requires some

[2] Derived from the Greek verb $\sigma\eta\mu\epsilon\iota\omega$, "to mark", and often described as any process that involves "signs". In the terminology of this paper, signs are categories.

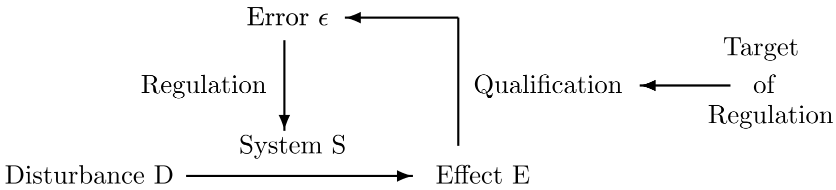
form of communication or coordination, revealing most clearly that information theory cannot possibly capture all aspects of communication.

So what does it capture? Specifying a set of possible messages amounts to being able to enumerate or list them. This can be done by encoding the messages in some alphabet (e.g. as strings of zeros and ones). Additional constraints can be added as well, so that only certain combinations of letters might be allowed, like words, and only certain combinations of words or word types, according to a grammar. In general, the more syntax is added, the further the set of "well formed messages" is restricted, which helps solve the reconstruction problem. Thus it becomes clear that information theory is about the *syntactic* aspects of language; it is about the rules and constraints that make communication possible in the sense of being able to properly encode and reconstruct messages. But messages in themselves do not carry any intrinsic meaning. In order to get at "meaning", we need to introduce another cybernetic concept, namely regulation.

2.2 Regulation

Regulation occurs in a system when the dynamical "behavior" of one subsystem, a "regulator", is such that it constrains the possible behaviors of another subsystem (the "regulated" system) in an end-directed fashion, that is, in order to achieve some goal or "target of regulation".

An important form of regulation both in artificial and in living systems is "error-controlled regulation". It is illustrated by the diagram below.



This diagram is a "flow-diagram" that shows how information flows over time. Imagine that "system S" is a house. The disturbance "D" might be a rise in outside temperature, perhaps because of a clearing of the clouds bringing out the sun. Depending on the specific properties of the house system (how many windows it has, whether the curtains are closed, etc.) the external disturbance has a certain effect E on the temperature inside the house. The inside temperature is then "qualified" by comparing it to a target temperature, say 20 degrees Celsius. If the actual temperature is above the target temperature, then it is qualified as "too hot", which indicates that a regulatory action should be taken in order to achieve the target. For instance, the regulatory system may decide to close the curtains, or turn on the airconditioning etc., thereby changing the properties of the "house system" in an end-directed way.

In sum, then, regulation is an end-directed process, in which regulatory actions are "chosen" depending on incoming disturbances and how they can be countered. It rests on some of the issues of semantics, such as categories and their qualification. We discuss these issues in more detail in the following.

2.3 Categories

We may begin by asking what may constitute a "disturbance" or "effect" etc., in the diagram of error-controlled regulation. In the example of a temperature-regulated house, they were "temperature quantities". A quantity is already a pretty advanced concept however. They are not just primitive categories or observable "distinctions", but involve a measurement process. A measurement, that is the determination of some quantity, always involves a mapping between what is being measured and some reference, which in principle may be fixed arbitrarily.

The measurement processes are not explicitly included in the diagram because, strictly speaking, they are not required. A disturbance may be anything which, through some "system", causes observable effects or "potentially meaningful distinctions". Consider for instance a machine or tool. Imagine that, due to some "disturbance", some part of the machine is broken. The effect in this case is a simple distinction between a working or a broken tool. If this is qualified as undesired, a repair action may be taken. One such action might be the replacement of the broken part. This is essentially a regulatory or end-directed action.

Thus the main ingredients of the error-controled regulation diagram, are distinctions and arrows that represent cause-effect relations between them.

2.4 Arbitrariness

The usual conception we have of cause-effect relations comes from physics and can be summarized by the diagram below.

$$\text{Cause C} \xrightarrow{\text{Law L}} \text{Effect E}$$

Here, L is called a "law" because it is "fixed", that is, it is ultimately reducible to the laws of physics. This assumption is what characterizes physics and at the same time delineates the phenomena covered by it, namely what we call "physical" systems. But, as discussed in the introduction, language is arbitrary, and therefore cannot be reduced to the laws of physics. So we must extend our conception of causality by allowing that the "law" L is also an "effect" itself. Let us first specify more rigorously what we mean by that.

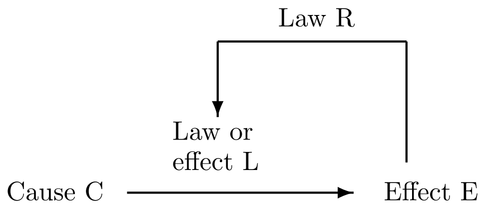
Even in physics, speaking of a cause-effect relation implies that without the cause, something else would have happened. Thus, both the cause and the effect in the above diagram can be conceived of as "categories" or distinctions providing information. Taking this as the minimal definition of an effect, it follows that we must consider the possibility that the law L is not just fixed, as in physics, but may also be determined by some other "cause" A and law R:

$$\begin{tikzcd}
 & \text{Cause A} \arrow[d, "\text{Law R}"] & \\
 & \begin{array}{c}\text{Law or}\\ \text{effect L}\end{array} & \\
\text{Cause C} \arrow[rr] & & \text{Effect E}
\end{tikzcd}$$

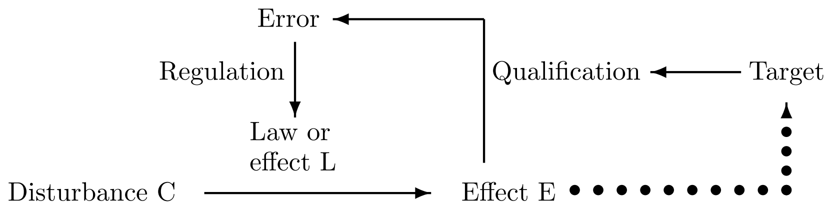
This diagram implies a cause-effect relation between a cause C and an effect E that nevertheless could be otherwise, and thus captures the essence of "arbitrariness". We can also feel the breath of an infinite regress here, because if we now want to specify what causes the "effects" A and R in the above diagram, we are forced to introduce yet other cause-effect relationships, and thus, it seems, yet more "causes" etc.

2.5 Closure and Self-regulation

An infinite regress can easily be avoided however by identifying a cause and an effect, thereby "eliminating" an unknown. This is what Robert Rosen in his relational biology calls a "closure to efficient cause" [Rosen, 1991, Wolkenhauer and Hofmeyr, 2007]. In the simplest case, from the extended cause-effect diagram, we arrive at the diagram below:



This diagram looks very similar to that of error-controled regulation. There is an important difference however: the diagram of error-controled regulation includes a "target of regulation", whereas here it must be conceived of as part of the effect. This can be seen most clearly in the diagram below.



This is the error-controled regulation diagram which, like the diagram above, specifies cause-effect relations. In addition, a dotted line now indicates that the effect E determines the target of regulation, thereby achieving a "closure". What Rosen showed, was that the "effect" can not just determine the target, but can *be* the target, even though this means there is then an impredicative! What does this mean?

The target of regulation is required for qualification. Through closure, that is by identifiying it with the effect of disturbances and regulation, the capacity to qualify is thus set as the reference of qualification itself. That is, the target of regulation has become the capacity to sustain categories, to qualify them, and to make informed decisions in order to persist or "survive" as a system with such capacities. The diagram obtained through closure therefore contains a *self-referential system*, and we will refer to it as the diagram of *self-regulation*.

A simple example of self-regulation is the following. Imagine again that the cause C is a drop in external temperature. Through some sequence of events determined by L, the effect E is that a man risks freezing. Because of that, the man 'decides' to put more clothes on. By this the man changes the effect of the temperature drop on him, thus performing an act of self-regulation.

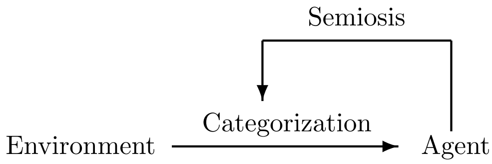
The concept of "self-regulation" or closure has turned up on numerous occasions in artificial life and in semantically oriented branches of biology [Letelier et al., 2011]. Von Neumann's theory of self-reproducing automata is a theory of self-regulation or closure [von Neumann, 1966]. Howard Pattee applied this theory to the biological cell, which uses information stored in DNA to achieve what Pattee calls semantic closure [Pattee, 1995]. Autopoiesis is also a form of closure [Maturana and Varela, 1980, Froese and Stewart, 2010].

These examples suggest that the concept of closure or self-regulation indeed captures many aspects of semantics. We argue that it allows to give a precise meaning to "problematic" semiotic notions such as "agency" and "semiosis" itself.

2.6 Qualification and semiosis

In the introduction it was mentioned that self-referentialities are often considered problematic because they lead to an infinite regress. We illustrate the issue by considering a concrete question concerning a concrete category. The question is "when has some thing the quality of being a 'hammer'?". We could answer that it should have the characteristic properties that make something suitable for 'hammering', so it must consist of a 'head', preferably something hard and heavy, and a 'handle'. A shoe could be a useful hammer on some occasions. In this case one probably would use the shoe's heel as hammering head. However, there is nothing intrinsic in that part of the shoe that grants it this quality. If the same piece of wood (assuming that it is made of wood) were attached to a piece of iron, it might loose the quality of 'head' and receive the quality of 'handle' instead. So far we have illustrated nothing more than the fact that categories are inherently relational, because the notions of 'hammering-head' and 'hammering-handle' can only be defined in relation to each other and the notion of a 'hammering'. The point is that the notion of 'hammering' is itself a category, which in turn can only be defined in relation to, e.g., a 'nail' and yet another category that captures the purpose of hammering, e.g. crafting a piece of furniture etc. An infinite regress unfolds, in a way that strikingly resembles current attempts in artificial intelligence and linguistics to get a hold on semantics by introducing ever more syntax.

Let us now investigate the issue from the perspective of cybernetics, particularly through the concept of self-regulation. The diagram of self-regulation is repeated below, but we have taken the liberty to rename some of the entities involved.



For this we need to agree to call disturbances "environment", the effect "agent", the proces by which external disturbances affect agents "categorization", and the activity of changing this process by and to the benefit of the agent as "semiosis". Without doubt, there is much to say against this. But at least, this way it is clear what the meaning of these "problematic" notions may be. An agent is anything with the capacity to regulate its categorization of events, that is, how it is affected by the environment. Furthermore, the way in which an agent "perceives" the environment, that is how it observes and maintains categories, now is part of the categorization process, something which resonates with the other issues discussed so far.

Things appear not so problematic anymore. Part of the reason is that the self-referentiality that characterizes semantics now is captured through a closed loop or "closure" of causes and effects. The infinite regress is still there, but it takes place over time. In this way, the "highest level" functionality to which the infinite regress of "lower level" functional relationships in living systems converges, can ultimately be provided by the theory of natural evolution, which essentially also requires that living systems are systems that are able to reproduce – and hence "persist" or self-regulate – in spite of selection and of the natural tendency of things to "disintegrate" according to the second law of thermodynamics, see also [De Beule, 2012a]. Another reason is that all aspects involved have been made explicit, and there does not seem to be any need to introduce anything else. Thus, things seem to fit together nicely. It is for these reasons that we think that the diagram of self-regulation captures the essence of semiosis.

The main point of this part has been to show that it is insightful to approach the problem of semantics from the perspective of cybernetics. In particular, it was shown how the concept of self-regulation captures many of the defining properties of semiosis, allowing us to clear up much of the confusion that often surrounds them. All this, we argued, in turn is crucial for arriving at a proper understanding of the phenomenon of language. It is however only part of the story. The other part is the distributed and collective or "conventional" character of language. In order to get at that, we must place the cybernetic account in an evolutionary perspective.

3 Steps Towards a Theory of Macro-Evolution and Language

3.1 Evolutionary Cybernetics

Cybernetics and the theory of regulation are closely related to general systems theory, and in this sense already take a dynamic or "evolutionary" perspective. However, tackling the problem of categories and the evolution of language as a coordination device requires that we incorporate the theory of *natural* evolution as well. The functional or semantic character of language is only part of the story, the other part is that language is the result of conventionalization and coordination mechanisms.

Evolutionary cybernetics is the theory that combines the ideas of cybernetics with those of evolutionary biology. In general, it tries to give a scientific treatment of the general nature of evolution, of thinking, of language and even of science itself, in abstract terms and general principles [Turchin, 1977, Heylighen et al., 1991].

3.2 The Beginning: Life Itself

The starting point of our evolutionary account coincides with that of life itself, at least if it can be identified with the appearance of the first "self-regulatory" systems. We continue by introducing the notion of "essential parameters". This is a cybernetic notion that captures the essence of self-regulation in a precise way and consequently turns out to be very useful for analyzing the evolution of such systems. In the words of [Ashby, 1954, 2/14]:

> "that a subsystem should keep its integrity, that is not to disintegrate but remain as a subsystem, certain parameters must remain within certain "physiological" limits. What these parameters are, and what the limits, are fixed when we have named the subsystem we are working with."

In other words, to identify a subsystem in a larger system, one must find a set of parameters that determine a region in 'configuration space' (the space of all possible configurations the complete system can be in) in which the subsystem can reasonably be conceived of as a subsystem – reasonable in the sense that it can be localized as a more or less independent subsystem. For instance, any system existing on earth today has temperature among its essential parameters, because if the surrounding temperature rises above a certain limit no earthly subsystem will be able to persist.

The notion of "essential parameters" is illustrated in Figure 1. The figure essentially shows a diagram

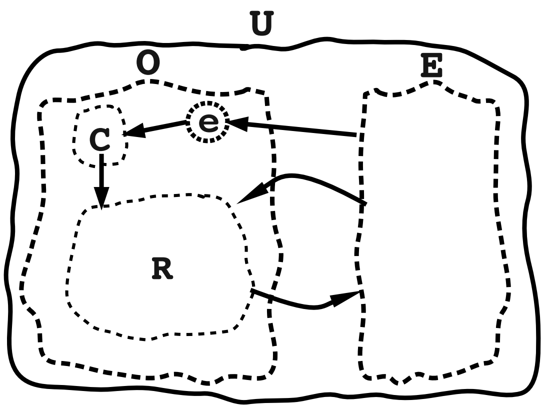


Figure 1: Illustration of the cybernetic concept of essential parameters. A system `U` consists of two subsystems: a self-regulating subsystem `O` in an environment `E`. The part marked `e` represents the set of essential parameters of subsystem `O` (partly) under that system's own control. `C` is the controlling part that, through the reacting part `R`, manipulates the environment in order to regulate the essential parameters.

of error-controlled regulation involving an agent or organism "O" and an environment "E". Crucially, the "error" that steers regulation are the essential parameters of the organism subsystem. As such, the target of control of the organism system has become the persistence of the system itself. Via the concept of essential parameters we thus include the sort of self-referential or closure relationship that is characteristic of semiosis.

3.3 Evolution

The capacity to persist is not the only thing that characterizes life on earth. Life also "evolves", it seems to grow in both diversity and complexity, and in the scale and degree of adaptivity. According to standard evolutionary theory, change is based on variations or "mutations" that occur during reproduction. Increased adaptivity then is the result of the interplay between variation and selection, that is the gradual replacement of "less adapted" by "better adapted" replicators. But what does "better adapted" mean in the knowledge that what is being selected for is the capacity to self-regulate? It must be increased self-regulatory capacity.

There are basically two ways in which the self-regulatory capacity of an evolving system can be increased. The first is through learning to react more appropriately to environmental disturbances. Thus, the system might try out a number of different responses to some incoming signal and select the one which seems best. Learning, in this sense, is a *reduction* in complexity because it is characterized by an increase in determinism or maintained "cause-effect" relations.

However, this kind of learning presupposes that the system can recognize signals, and that it already has identified a number of possible responses. In other words, this kind of change through a process of learning or adaptation presupposes the existence of (at least potentially) useful categories. Furthermore, by the cybernetic law of requisite variety, there is a limit to the amount of control a system can achieve in this way, which is precisely determined by the number of categories available.[3]

The second way in which the self-regulatory capacity of a changing system can be increased is by increasing its variety. This corresponds to the creation and incorporation of new categories by the system. It is not entirely clear yet how such an event could occur, because by its very nature it resists formalization. How can we make a model of something that gives rise to something absolutely novel, and hence cannot be part of our model? We might have to extend our conception of what a formal model is to something dynamic itself. The target could then be to *build* systems that perform semiosis and create absolute novelties, that is, "truly creative" systems [De Beule, 2012c]. As suggested by the characteristic properties of semiosis, creating a category and qualifying it are part of a single process. Thus, a possible strategy might be to build a system that constantly tries out random ways to detect as of yet unqualified "structures" or "patterns" in the stream of percepts, and see if they may be useful for regulation. This might be done with the concept of "predictive information" [Bialek et al., 2001], which is a generic way to qualify the potential usefulness of information, that is the potential of information to *become* meaningful when coupled to the right regulatory response. Attempts in this direction are actually taking place and look very promising, see for instance [Ay et al., 2008]. A related but perhaps more intuitive scenario that can lead to an increase of a system's variety is the idea of supplementation [Ashby, 1954] or extension [Clark and Chalmers, 2006], which essentially boil down to the incorporation of external variety through "tool usage".

3.4 Tool Usage, Specialization and Extension during Metasystem Transitions

A "tool" can be defined as anything that enhances the control of a self-regulating system over its essential parameters, and through that over its own "survival" or persistence. Let us define this notion of "tool" further. Similar to what was already discussed concerning the quality of being a "hammer", so is the quality of being a "tool" not intrinsic to objects. Rather, it lies in the way that objects are put in relation to each other, and in the end-directed way objects are used. The notion of "tool" is itself a functional notion, and such notions are always "assigned" or "granted" through a process of semiosis. But semiosis requires variety. The point, for now, is that tools do not just enhance variety, their manufacturing, maintenance and usage also *consume* variety, as rules must be remembered and applied for producing, maintaining and even for just operating it. The essence of a good tool is of course that it returns more variety than it consumes.

The amount of variety a tool may return depends heavily on the context. A modern computer might be a highly efficient tool now, but would have been useless a mere 100 years ago. More generally, not counting the variety invested in its manufacturing and maintenance, this amount is typically very high for highly

[3] Variety is related to information (in the Shannon sense), e.g. if a message is received from a *variety* of V messages, then $log_2(V)$ bits of information is received. The law of requisite variety is related to Shannon's tenth' theorem which limits the rate of communication over a communication channel of limited capacity.

"specialized" tools. Those are tools which are very well "targeted" towards solving a particular problem that would be difficult to solve without the tool. Specialized tools, however, typically require other tools for maintenance, and particularly for manufacturing. It follows that the most probable scenario of tool usage is one of an ever growing hierarchy of increasingly specialized tools. Each new level imposes new functional relations upon the lower levels by constraining them and controlling for what purpose and thus how they are used.

Now "tools" are systems and, like all systems, are dependent on essential parameters. But unlike self-regulatory systems, they have no control over these parameters. Instead, their "persistence" depends on whether they continue to be manufactured and repaired. Thus "oldfashioned" tools tend to disappear and become replaced by newer, more efficient tools. Nevertheless, as long as a tool remains useful, that is as long as a self-regulatory system can profit from using it in return for manufacturing and maintaining it, the tool continues to persist as a system, and may form the basis for an even better tool.

So imagine that a system's net gain in self-regulatory capacity as the result of tool usage is positive and reliable, so that the self-regulatory system may consider to "specialize" by investing some of its now available regulatury capacity in other tasks. For example, since the "invention" of fire, humans have gradually "outsourced" digestive functions to cooking, a likely advantage of which was an enhanced supply of protein, allowing an increase in brain size. In consequence, however, it seems that we can nowadays no longer survive on unprocessed food, and in this sense the concept of cooking and the tools that come with it have become an integral part of ourselves. This is an example of how evolution may lead to "extension", which is the process by which a self-regulatory system may increase its variety with that of another system or tool through complementary processes of specialization, until they effectively become a single, larger self-regulatory system. This is also a first example of a so called metasystem transition, that is a transitions in which a new level of control and hence new functional relationships emerge between two or more systems. In the words of Turchin, who introduced the concept [Turchin, 1977]:

> "The metasystem transition creates a higher level of organization, the metalevel in relation to the level of organization of the subsystems being integrated. From the functional point of view the metasystem transition is the case where the activity , which is characteristic of the top control system at a lower stage, becomes controlled at the higher stage and there appears a qualitatively new, higher, type of activity which controls the activity."

Metasystem transitions are characterized not only by the appearance of a "qualitatively" new level in the hierarchy of functional relationships, and hence increased levels of coordination between system, but also by the appearance of new "codes". The code, in the case of tool usage, consists in the recipy or "protocol" for manufacturing, maintaining and operating the tool to which the self-regulatory system must commit. The relation with language might not be so clear yet. But this will come when we consider other metasystem transitions that not just involve the interaction between a self-regulatory system and a "tool", but between two or more self-regulatory systems.

3.5 Coordination

After the previous section, our model of evolution predicts the selection of systems with an increasingly powerful capacity for self-regulation by means of ongoing extension through a process of metasystem transitions. With every new transition, more specialized functionalities or qualities arise as absolute novelties. This also has an effect on the essential parameters of systems. Not just on their target values, but on the set of parameters itself, which must necessarily increase with the number of functional relationships that need to be maintained. It is also evident that if a system "extends" and thus *changes into another system*, its set of essential parameters must also change.

Another consequence is that, as systems "grow", they are bound to interact at some point. The next question therefore is what happens when two or more extending self-regulatory systems interact. In many respects, the situation is not so different from what occurs during the interaction with tools. So what was said in the previous section remains true, except that now *both* systems are self-regulating. In the case where the tool was a pure artefact there was no conflict between both systems, because the essential parameters of the tool system were under *full* control of the self-regulating system. Whatever happens, therefore, the tool-system could only benefit from its interaction with the self-regulating system.

But if the tool system is another self-regulating system, it has control over some of its own essential parameters, and these may not be the same as those of the first self-regulating system. Even worse, some parameter may be shared between both systems, but the range of "physiological values" vital to one system may be lethal to the other. In this case, there really is only one possible outcome: one of both systems must go extinct. This is the "simplifying" power of natural selection again which, just as normal learning, gradually settles on what works or is more "adapted", and eliminates what doesn't work. This finding, together with Mendelian inheritance and the idea of variation, can be considered as the core of Darwinian evolutionary theory. Like learning, it leads to the gradual adaptation of things.

Now let's see if we can go further. However sad the extinction or "de-selection" of some species may be, it also has a good side, because the elimination of one type of system also means the selection and thus further thriving of another. Neglecting the introduction of new variation due to mutation, this means that as selection proceeds, the number of conflicts between the essential parameters of the systems that remain will decrease. In turn, then, this means that as evolution proceeds, self-regulating systems will be able to extend themselves *with each other* and become parts of a larger self-regulating system.

Somewhat more formally, the fate of a self-regulatory system interacting with another self-regulatory system depends on how the essential parameters of both systems are related (see also Fig. 2). Specifically, if

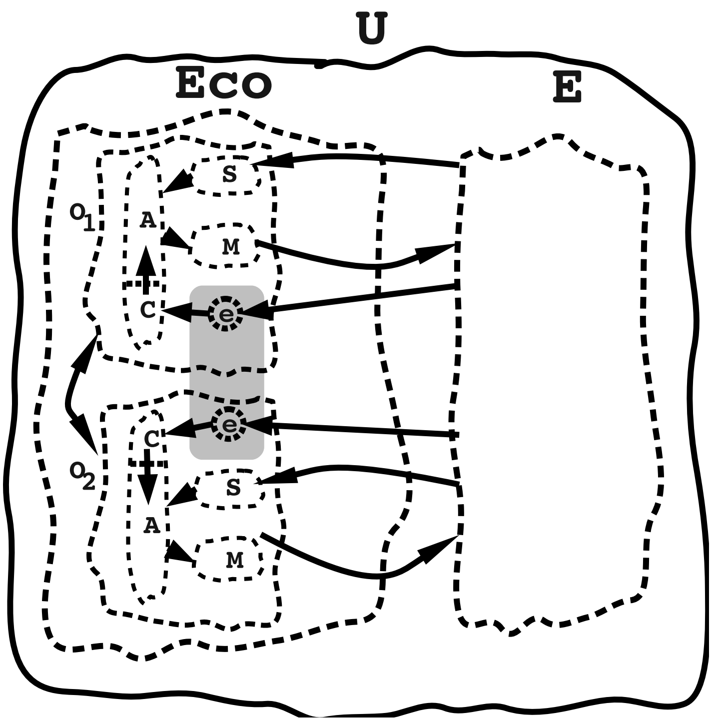


Figure 2: A system `U` of two self-regulatory systems O_1, O_2 interacting with each other and a shared environment `E`. Some of the essential parameters `e` may be shared between both systems, indicated by the grey box around them, which may have an influence on their mutual fate. Note that the reacting part `R` in Figure 1 has been decomposed into an `S` part representing incoming variety (signals), an `M` part representing outgoing variety (meanings), and a part `A` representing the "adapters" or cause-effect relations between them. Learning takes place when the control part `C` changes the adaptors.

there are no incompatibilities between the essential parameters of both systems, they may both continue to thrive and evolve. If, in addition, both systems *share* some of their essential parameters, they may actually benefit from coordinating their mutual regulatory capacity, because then the combined variety *per* essential parameter is increased, which is not against the law of requisite variety.

Thus, we conclude that it is perfectly conceivable that evolution leads to a situation where several systems, through mechanisms of specialization and differentiation, at least at a functional level, evolve into compatible and even complementary systems, using each other as "tools" until they become so important or "vital" to each other that they effectively become parts of a single, irreducible whole. In fact, this is not just a wild idea, it takes place in nature and is responsible for the evolution of absolute novelties, evidence for which are the famous major transitions [Barbieri, 1985, Maynard-Smith and Szathmáry, 1995]. Moreover, just as in the case of artefacts and protocols, a metasystem transition involving two or more agents gives rise to a new code by which the different systems can coordinate and fulfil their functional role in the new organization. Like Barbieri [Barbieri, 1985, Barbieri, 2008c], we propose to call this mechanism, which is responsible for the major transitions and the appearance of new codes, as "evolution through natural conventionalization".[4]

3.6 Natural Conventionalization and Language

We have finally arrived at the main topic of this special issue, namely language and coordination. In the previous sections, we have discussed the phenomenon of extension as a metalevel transition characterized by an increased degree of coordination and the appearance of an arbitrary "code" or interaction protocol. Is this all there is to say about language from the perspective of evolutionary cybernetics? In one way, yes, the appearance of language is a metasystem transition and in this sense not fundamentally different from other metasystem transitions that occured in macroevolution. But, then, what about the complexity and flexibility of human language compared to the complexity of other codes in nature?

In general, the increased arbitrariness and complexity of codes that arise as a result of the coordination between several agencies, when contrasted to the interaction protocols that arise during the extension of agencies with ordinary tools, is precisely due to the fact that they are not just the product of an integration between agent and tool but instead between two or more agents. Agents, as we have seen, are characterized by a regulatory capacity to make and maintain arbitrary "choices", to try out things and to see whether they "make sense" through learning (which might be normal evolution through variation and selection).

Recall that the main reason why two self-regulating systems may benefit from the integration into a larger whole is because, just as in the case of tool usage, it may increase their self-regulatory capacity, which is what they are selected for. But the total self-regulatory capacity of two systems does not increase by itself. If two identical self-regulating systems interact with each other for the first time, they will not have developed any categories or behaviors that are adapted to this new type of interaction. Initially, the agents will not yet have found any use for each other. Thus, although their joined regulatory capacity per essential parameter in principle may be increased (as they share some of them), the regulatory action of both systems is initially still more or less targeted at the same subset of parameters and in the same way. In order to change this, the systems must adapt to each other by specializing, so that their combined regulatory capacity is better targeted and thus more efficiently employed. This means that they must change or develop in complementary ways.

But next to becoming more "efficient", each of them will also become more dependent on the other, meaning that they need to commit to the fulfilment of the functional roles they are assigned in the larger whole. These roles are not intrinsic to the systems, but depend on the way they are integrated, and thus must be "communicated", just as the function of a "head" and a "handle" is communicated by the way in which they are put together and handled as a whole. As another example, during the first few cell divisions, all of the cells in an embryo have equal chances of becoming any sort of cell in the growing body, they are essentially "the same". As a result of random fluctuations however, certain regions of cells may produce slightly more of some hormone, causing a gradient in the developing embryo. This "signal" then tells different parts of the embryo to differentiate and develop differently. They must develop along very

[4]To be precise, Marcello Barbieri speaks of "natural conventions" instead of "natural conventionalization".

specific lines however in order to make up a complete and vital organism in the end. Particularly, they must comply to the "signal" by reacting "appropriately" to it, that is, in an end-directed or regulatory fashion, but now at a higher level of organization.

This interweaving of increased self-regulatory capacity by becoming part of a larger whole, while at the same time becoming less "free" and subject to the limitations imposed by a "higher" level of control, is the essence of metasystem transitions, and is the reason why such transitions always involve the appearance of new codes. Self-regulating systems are trying out random or "meaningless" actions. In the case that there is another self-regulating system around, however, the second system will also be trying out random categorizations of whatever the other system is doing. In this way, some action-response relationships, although completely arbitrary and intrinsically meaningless initially, might start to *become* meaningful. There is no maintained relationship between "cause" and "effect" initially, but by noticing a relationship that is randomly tried out, it now may start to *become* one. Such a relation "could have been different" and thus, like language, is arbitrary. Language, therefore, is the set of arbitrary categories and rules that reflect cause-effect relations in the world, specifically those that enable the control of other agents like oneself to engage in functional or joint-regulatory relationships. The emergence of control over these relationships and thus over "causes" and "effects" through communication is another example of a metasystem transition into a metalevel of coordination or organization, and language is the "code" that comes with it and enables it.

So far, what has been said does not just apply to language, but to any code that is the result of conventionalization processes that shape the interaction between any sort of agencies. In the case of language, however, the agencies are human beings, which are themselves already the result of many metaystem transitions. This is the reason why human language is not only more complex than the protocols of tool-usage, but also more complex than any other naturally occuring code so far, even those that are the result of coordination between "lower level" agencies. Another way of seeing this is the following. Recall that we arrived at the notion of self-regulatory systems by "closing" the diagram of error-controlled regulation, that is by identifying the target and effect of regulation. In this way, we were able to escape an infinite regress. However, it is also possible to close the diagram only after introducing more intermediate cause-effect relationships. From an evolutionary perspective, each level may then correspond to another metasystem or major transition leading to ever more complex but essentially self-regulating systems. As the agencies that coordinate become more complex, the processes of semiosis they exhibit become more complex as well, as will the codes that emerge out of their coordination.

3.7 Compositionality and Grammar

With respect to the complexity of language we may also gain some insight by considering some of the characteristic properties that seem to set human language apart from other biological codes. An example of such an approach is given in [Froese et al., 2012]. The fact is that the more closely we look at existing codes in nature, there is not so much of language that really passes the test of being uniquely human. All of them are arbitrary to some extent, and all of them are used for coordination and integration, illustrating that they are all parts of the basic process of life, which is semiosis.

Nevertheless, one thing that seems to set human language apart is its *compositional* character. In general terms this means that the meaning of an utterance is not just a simple "sum" or union of the meaning of its parts, but rather a "function" of its parts, which implies hierarchical "relations" between them. The important feature of compositional encoding is not just that it involves different orderings or other syntactic relationships, but that some of the meaning is conveyed *through* relationships, which are themselves categories but of a "higher level" [Tomasello, 1992, p.6]. It is often said that one "cannot point" towards a relationship, at least not in the same way as one can point to a "particular". This is true, to a certain extent, but that does not mean that relationships are not real, and thus cannot become recognized as useful categories. Relationships can be observed, and thus "recognized", "named" and "used". All that it take is a "sufficiently complex" process of semiosis, which is precisely what humans are capable of in comparison to "lower level" agencies.

So why could it be useful to raise relationships to the status of symbols themselves? The answer is simple: in order to convey relational information. It is not possible to convey relational information such as *cause-*

effect relations, or *relations over time* without them. Without compositionality, that is without grammar and grammatical constructions that express complex relationships between their parts, we would not be able to make a distinction between "agents" and "patients", or discuss events that occurred at another time, or in another place, the phenomenon of "displacement" which is considered another characteristic property of human languages [Hockett, 1960].

Grammar, in short, has all the characteristics of yet another metasystem transition: it brings about a new level of control, namely over that of relations and thereby over meanings of words in larger grammatical structures. It is because words are used in this or that grammatical construction that they receive this or that functional role or "quality". Hence, there is a shift in control for the sake of the creation of a larger functional whole, and therefore grammar itself is part of a "code" that results from a metasystem transition: it is the syntax by which humans agree to change the meaning of lower level "systems" of categories called words according to our theories of grammar.

4 Conclusion

We started the paper by identifying and discussing three open issues of semantics that, in our opinion, are hindering scientific progress in several respects, namely the issues of categories, of arbitrariness and agency, and of semiosis.

We have shown that cybernetics, particularly its concept of "self-regulation", is appropriate for approaching these issues. Based on this concept, we were able to give precise meaning to the semiotic notions of "agency", "categorization" and "semiosis" itself. An agent is a subsystem that interacts with its environment in an end-directed way, just as a regulating system is end-directed. Moreover, the target of regulation of an agent is the persistence of the agent itself as a subsystem in the whole. This requires that the agent has the capacity to categorize its environment, meaning that it must identify categories or "distinctions" that indicate "important choices" to be made with respect to the target of regulation, that is "survival". Semiosis is then the process of discovering novel distinctions or affordances (and thereby qualifying them as such).

We then brought evolution into the picture. Starting from the assumption that selection favors increased self-regulatory action, we proposed an evolutionary scenario that explains some of the remaining puzzles of evolution, such as the major transitions in macro-evolution as well as language. To recapitulate, a system might increase its self-regulatory capacity through mechanisms of variation and selection or, more generally, through "learning". This only works up to a certain limit, however, called the variety of the system. But this variety can also be increased, namely through semiosis, or the creation of new categories and functions, e.g. by inventing or refining tools. This leads to the "extension" of systems *into* their environment.

It is also possible that two self-regulatory systems extend into each other, specifically when they share essential parameters, through mechanisms of specialization and coordination. When this happens, a metasystem transition occurs, and the subsystems become a single, novel self-regulatory system that brings and maintains its own categories and functionalities. It also brings increased coordination (each subsystem must perform its new functional or end-directed role as part of the whole, which now becomes the new target of regulation) communicated through a code or "language". This language will be arbitrary, because it embodies cause-effect relations maintained by agencies for the sole purpose of coordination. It is, in other words, the result of *conventionalization* processes by which the different agents align their behavior to fit in the emerging whole. The mechanisms by which metasystem transitions proceed can thus be called natural conventionalization.

One conclusion, then, is that natural selection and natural conventionalization are complementary mechanisms of evolution, the first accounting for the gradual adaptation of existing species through variation and selection and the second for the origin and fixation of absolute novelties at higher levels of organization through metasystem transitions. These mechanisms are not independent however, and their interplay must be taken into account in order to obtain a full understanding of evolution. Language, just as the other "codes of life", is a product of this interplay.

Another conclusion is therefore that the evolutionary mechanisms that explain language are not qualitatively different from those that explain other instances of coordination in the biological world. Rather, the difference lies in the levels of organization at which coordination takes place, and in the different time scales at which it unfolds (i.e. genetic vs. cultural).

Finally, we hope to have shown rigorously that the view purported by this special issue – that language should primarily be characterised as coordination – is in fact not just an alternative view, but the only view which offers a *complete* account of language.

This is as far as our evolutionary cybernetic account on language and coordination goes. We do not claim to have solved all issues raised, and it is not inconceivable that some readers are left with a certain feeling of disappointment, for it is not clear "how to proceed". We would like to direct those readers which are eager to find out how these concepts might be applied in practice to a case study on the emergence of conventions to coordinate behaviour as a species, details of which we were unable to include in this paper due to space limitations [De Beule, 2012b].

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