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Löfgren, Lars

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LARS LÖFGREN
University of Lund

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TOWARDS SYSTEM:
From Computation to the Phenomenon of Language

LARS LÖFGREN
University of Lund, Sweden

Abstract

Early cybernetics emphasized control and communication in the animal and the machine. Subsequent understandings of linguistic phenomena in the animal have shown them not to be reducible to purely mechanistic models. The linguistic complementarity, with its possibilities for transcendence, provides such an understanding, indicating relativistic approaches within modern systems theory. Comparisons are made with Bohr's concept of complementarity for quantum physics, again an area where linguistic objectifications are developing. The linguistic complementarity is taken as a basis for a general concept of language, permitting particularizations like programming languages, formal languages, genetic languages, and natural communication languages.

1 *Introduction*

Undoubtedly, there is a tendency in modern systems thinking towards including ourselves, as linguistic human beings, into the nature that we observe and try to understand in objective, linguistic terms. That is, terms which usually obtain a mathematical nature, like in descriptive, formal theories. We thus face a situation, where attempts at objective description enforce us, in our roles of describers, to distance ourselves from this nature of which we, at the same time, want to be a part.

From this autological predicament, it appears reasonable that we, by contrast, should find it comparatively easy to reach scientific insights into a physical nature, i.e., a nature that only contains physical, nonlinguistic, processes. In that case, there is no immediate argument against a language with a scientific expressibility that is universal with respect to physical phenomena, because the domain of physics does not include that language. Not that it is not somewhat of a mystery that nature lends itself so well towards being fragmented into a physical, nonlinguistic, domain and a remainder including phenomena of language. Indeed, we have in Bohr's concept of complementarity for quantum physical phenomena a complicating step towards including a linguistic fragment into the physical.

Nature, containing phenomena of language, will be the main object for this essay in autology. We will unfold the underlying problem of self–reference in terms of a hierarchy of languages, where it may well be within the expressibility of a higher language to completely describe a lower level language. Furthermore, higher level languages may have autological properties, allowing them to partially describe themselves.

By studying specific embodiments of language we will get insights that are naturally generalized, on an inductive basis, towards a general concept of language. Experiences from programming languages, formal languages or genetic languages will suggest that we settle the objectification problem for language, i.e., the problem of characterizing a general concept of language, in terms of a linguistic complementarity. Thus, we will objectify language as a *phenomenon* in a Bohrian spirit, namely as a pair of description and interpretation processes that are complementary within the language. This means that no language can be completely analyzed, within itself, into its syntactic and semantic parts. The concept of language will be a wholistic system concept. The linguistic complementarity may (unlike Bohr–complementarity) be transcendable, however, meaning that an object language can be completely described, in terms of its description and interpretation processes, if a metalanguage avails itself.

By comparison, the concept of computation can be more easily objectified in terms of machines, Turing machines for example. Here, we have a more physical-like situation with a class of well–defined machines, whose computation behaviours are precisely the partially computable functions. The correspondence between the class of partially computable functions and the class of Turing machines, usually formulated as an existential representation theorem, is a metaresult (yet derivable by a self–application of Turing machine theory). The problem of how to go beyond the mere existence of a Turing machine that computes a given computable function, and actually consider how to derive such a machine from a knowledge of the function, is usually abstracted from the domain of computation (although not always from the domain of computer science).

Not until this latter problem or, equivalently, the problem of how to program a universal Turing machine is recognized, do we encounter a phenomenon of language, a programming language — for which the linguistic complementarity obtains.

Proceeding from computation to mathematics in general, we meet various attitudes towards the objectification problem. One such is to suggest that the problem of objectifying mathematics is not itself a mathematical problem, and thus irrelevant to mathematics. Another is to objectify (branches of) mathematics as formal languages in the sense outlined, namely as phenomena for which the linguistic complementarity obtains. This latter attitude leads into metamathematics as a foundation for the autology of formal languages.

The objectification of language as a phenomenon is particularly useful in understanding other systems phenomena, like induction (including learning), fragmentation (including concepts of relevance and irrelevance), artificial intelligence, etc. There is a tendency, otherwise, to deal with these linguistic phenomena in terms of a mathematical knowledge, that has developed over the years when the physical studies dominated the scientific and mathematical development. It is then easy to abstract from properties of these concepts, that cannot be expressed within the available formalisms, thereby distorting the true nature of the concepts. Examples of such too restricted fragmentations we do have in "information theory" (which, if restricted to Shannon theory which abstracts from semantic contents, is insufficient for a proper development of information as the linguistic phenomenon it naturally is), "artificial language" (which, in abstracting from meanings of sentences, is no language), "artificial intelligence" (which, as present day courses in computer science, has little if anything to do with intelligence). By contrast, a proper autological development of these concepts, i.e., developing them in terms of a metamathematical background knowledge, may provide an insight into their proper linguistic nature.

From an historical perspective, we observe how Wiener, in his cybernetic steps towards language with focus on communication and control, adds a chapter on learning and self–reproducing machines into the second edition of his book *Cybernetics* [36]. Also Turing, in his paper on artificial intelligence [34], ends up with learning as key phenomenon. Yet, neither of these early works develops any metamathematical insights into learning. Rather, the early discovered mechanisms for feedback control and for computation were thought responsible also for the more advanced forms of communication and control in the animal. By contrast, newer metamathematical insights into learning and into the genetic processes as description and interpretation processes, with language a complementaristic phenomenon, provide a relativistic understanding of these phenomena. Eventually, their inherent autological nature can be unfolded in terms of degrees of *non*computability — again a reminder that a big step is taken in passing from computation to the phenomenon of language.

2 *Computation*

Mathematical activity is in general too complex to be taken, itself, as an object of mathematical study. However, fragments of it have been understood through philosophical studies, and sometimes even through metamathematical. Effective calculability is an example of an intuitively understood part of mathematical activity, of which a fragment, namely (Turing–)computability, has been extensively studied in metamathematics. Effective calculation refers to the activity performed by a human computor, engaged in the evaluation of, say, numerical functions defined only in terms of well defined rules of calculation, without preset limits for the length or time of the calculation process except that it be finite. A well defined rule of calculation refers to a finitely describable rule whose interpretation, or execution, is uniquely and objectively determined (by the computor or by simple mechanical means, including paper and pencil). According to the *Church—Turing Thesis*, the class of functions that can be sufficiently well defined to be effectively calculable in the above sense, are precisely the recursive functions. Again, the (partial) recursive functions are equivalent to the (partially) computable, or Turing–computable, functions. Notice that this last equivalence is a strict mathematical result, whereas the Church—Turing Thesis is an hypothesis, let be well supported.

Obviously, the Church—Turing Thesis implies a limit to human calculability. Namely, that nonrecursive functions — which indeed do exist — go beyond the power of human calculability, even when preset limits as to the length and time of the calculation are abstracted away. Very strong beliefs in the thesis have resulted in suggestions actually to define the effectively calculable functions as the recursive functions. That would seem to be to go too far, however, in particular in the light of recent discussions of calculability like in [8] and [5], where it is essential that we keep our intuitive notion of effective calculability free as an object of independent understandings. In the context, we also want to remind of a comment of Post, who did fundamental works in this area, contemporary and similar to Turing's and Church's. In [26] he writes:

> "Actually the work already done by Church and others carries this identification [of effective calculability with recursiveness] considerably beyond the working hypothesis stage. But to mask this identification under a definition hides the fact that a fundamental discovery in the limitations of the mathematicizing power of Homo Sapiens has been made and blinds us to the need of its continual verification."

In a positive direction, the Church—Turing Thesis suggests that human calculability, as part of the human mathematizing activity, really can be modelled in mechanistic terms, namely as Turing machines. Recalling the setting of the calculability problem, this does not seem an unreasonable proposal. After all, the problem only concerns the evaluation of those functions that can be so well defined, in terms of objective instructions, that the evaluation can be carried out without processes that need further instructions. In other words, the functions under consideration are already assumed to be given in terms of descriptions (algorithms, programs), that can be "effectively" interpreted.

Thus, the Church—Turing Thesis only concerns the interpretation of well defined function descriptions, like algorithms and programs, and says nothing about the process of how to derive such descriptions from a mathematical knowledge of the functions. As we are about to see, this latter description process — indeed a central linguistic process — is an example of a mathematical activity of such a complexity that it cannot itself be reduced to a computation problem.

For a philosophical discussion of the Church—Turing Thesis we refer to [29].

3 *Towards Language via Universal Turing Machines*

The partial recursive, or partially computable, functions, $\psi_z(x)$, have an interesting normal form, namely:

$$\psi_z(x) = V(\mu y\ T(z,x,y)),$$

where $T(z,x,y)$ is the so called Turing machine predicate, μ is a minimalization operator, and V a recursive function. The intended interpretation of the T–predicate is: "Turing machine Z, identified by the Gödel number z, performs upon start from the argument x a computation sequence Y, identified by the Gödel number y". Although T is a metapredicate in that it describes how a Turing machine interprets a description, x, it is itself back on the level of computability (an even primitive recursive predicate). $\mu y\ T(z,x,y)$ is the unique smallest y such that $T(z,x,y)$ holds true. $V(y)$ defines the value of the last segment of the computation sequence Y, i.e., the value of the function $\psi_z(x)$, computed by the Turing machine Z.

Now, since the T–predicate is recursive, $\mu y\ T(z,x,y)$ is partial recursive (the minimalization operator preserves partial recursiveness), as well as the normal form $V(\mu y\ T(z,x,y))$ itself. In other words, the normal form for the partial recursive functions is itself partial recursive! This is a remarkable situation. For other classes of objects that possess a normal form, that form is of a higher type than that of the objects in the class. Compare, for example, the normal form:

$$a_n x^n + a_{n-1} x^{n-1} + \cdots + a_1 x + a_0,$$

for the polynomial functions it represents upon particular choices of the variables n and a_i. Here the normal form *is not* itself a polynomial in all its free variables, but an exponential. By contrast, the normal form for the partial recursive functions *is* itself partial recursive in all its free variables, z and x.

An obvious consequence is that there are particular Turing machines U which compute the normal function itself:

$$\psi_u(z,x) = V(\mu y\ T(u,\langle z,x\rangle,y)) = \psi_z(x).$$

Such a machine, with identifying Gödel number u, is *universal* in the sense that it computes any function $\psi_z(x)$ that can be computed by Turing machines Z at all. We simply have to provide U with the program $\langle z,x\rangle$, to have U simulate Z in computing $\psi_z(x)$.

The ordered pair $\langle z,x\rangle$ is a very special form of program. For other universal Turing machines there may be other forms. With $p(z,x)$ for a program of $\psi_z(x)$, we say that a Turing machine U is universal if, for all z and x, $\psi_u(p(z,x)) = \psi_z(x)$, provided that the programming function $p(z,x)$ is recursive.

With the requirement that the programming function $p(z,x)$ be recursive we secure that the complexity of programming U, from the $\langle z,x\rangle$-information of $\psi_z(x)$, will be of a lower type than that of the universal computation performed by U. If no such restriction were enforced, we could face a situation where practically all of the computation had to be done by the programmer in computing $p(z,x)$ and practically no computation by the universal machine U. However, with the above simple requirement that $p(z,x)$ be recursive, which is due to Davis [4], a desired type distinction is obtained. The domain of ψ_u will then be creative, i.e., of a higher complexity class than that of the domain of the recursive p (see [13]).

Notice that at this point we are taking a major step over from computation to the phenomenon of *language*. The very idea of a universal Turing machine that can be programmed to compute any computable function is at the same time an idea of an interpretor that can interpret descriptions in the form of programs. In the phenomenon of universal Turing machines, we have all the ingredients that will be suggested as essential for a general concept of language (Section 5). Of course, these ingredients will here appear under very specific forms (that will be abstracted in Section 5). We have sentences, or descriptions, in the form of programs, $p(z,x)$. We have interpretations in the form of function-objects, $\psi_z(x)$. We have the interpretation process, that realizes the interpretation function, in the form of a computation process, Y. We have the description process, that realizes the description function $p(z,x)$, in the form of an assumed programming process.

In this universal machine paradigm of a phenomenon of language the assumed programming process (description process) is of a specialized nature. It is assumed recursive and to operate on the variables z and x. This means that the description process is assumed to start out from an object ψ_z, which is already known in terms of its identifying Gödel number, z. In this case the whole description process, which computes the p–function, reduces to a mere coding process, that surely can be stipulated recursive.

In the general linguistic case, however, a description process starts out from an object that is but partially known. Known, that is, through observation. As we know, only a part of the properties of an object can be directly observed. Further properties are inferred, deductively as well as inductively. A description process is essentially inductive. This is what makes it, in general, complex beyond reach for full description in the language of which it is a part! Compare the linguistic complementarity.

We face this more general case of inductive description processes in contexts of programming languages where programmers, as is most often the case, are confronted with only a partial knowledge of the objects they are about to describe, or to program. The programming process is then, unlike the case of a recursive $p(z, x)$–programming, of such a complexity that it cannot be completely handled within the actual programming language. The programmer must here use human capacities beyond description in the programming language, or develop a metaprogramming language. Compare the possibility of transcending the linguistic complementarity.

4 *Partial Introspection of Formal Languages*

Although a full description of a language cannot be generated in the language itself, partial introspection is a linguistic possibility.

For such possibilities it is essential not to conceive of the description—interpretation relation, that constitute a language, in terms of a conventionally defined relation. That is, with a priori defined domains and codomains on which the relation is secondarily defined. That would interfere with the idea that a language is itself a vehicle for definition and for laying down meanings, not excluding meanings of parts of the language itself. A meaning that has never been conceived before may well result from an interpretation process in a given language. Then, the interpretation process is conceived of as a primary linguistic process, whose result is the newly conceived meaning.

It is essential for our whole conception of language, that the description—interpretation relation, which constitutes the language, be thought of as primary processes, eventually of a recursive nature. Their domains of application are secondarily determined as the set of entities on which the processes will function (terminate). Under this understanding of a language, it may well be the case that description—interpretation processes can be applied to themselves, just like a Turing computation process, defined by its Gödel number z, may well terminate on z itself as argument.

For an understanding of the possibilities of partial introspection of formal languages, the so called *recursion theorems* (cf [13], [28]) are quite helpful. One such is the following (cf [30]):

> *Diagonalization Theorem.* Within a first order language L, rich enough to allow expression of the recursive relations in a theory T, there is, with every formula Wx, a sentence φ, with Gödel number $\ulcorner\varphi\urcorner$, such that:

$$\vdash_T (\varphi \equiv W\ulcorner\varphi\urcorner).$$

(As usual, the metasentence $\vdash_T \psi$ means that the object sentence ψ is provable in T). The fixed point sentence φ thus says of itself that it has, by provable construction, the property Wx. Cf the following sentence, in natural language, which is a fixed point to the property of having a given number of letters:

"*this sentence contains precisely fortyfive letters*".

Of course, the Diagonalization Theorem does not say anything about the provability, or of the truth, of the fixed point sentences themselves. (In the above example from natural language the fixed point sentence happens to be true.) But it shows that fixed point sentences can be constructed to obtain a meaning according to any given W.

In natural language we can freely construct self-referential sentences like in the above example by using indexicals, such as "this". But to establish reference by pointing to the object referred to, requires us to go outside the sentential domain. Accordingly, it is very difficult to explain, within a sentential domain, the meanings of indexicals. However, as seen by the Diagonalization Theorem, by narrowing down the language to a formal language, such as L, meanings can be established also for certain forms of partial self-reference.

As is well known, it is possible to express the metapredicate "the sentence, with Gödel number x, is provable in T", by a certain formula $Pr\,x$ in L. The fixed point sentence to $Pr\,x$ is a so called *Henkin sentence*, h, which thus says of itself that it is provable:

$$\vdash_T (h \equiv Pr\ulcorner h\urcorner).$$

Henkin's question, whether h itself is provable in T, was answered in the affirmative by Löb (cf Section 7 for a proof).

The fixed point sentence to $\neg Pr\,x$ is a *Gödel sentence*, g, which thus says of itself that it is not provable in T:

$$\vdash_T (g \equiv \neg Pr\ulcorner g\urcorner).$$

Assuming certain completeness and soundness properties for the T–axiomatization, Gödel showed g to be completely independent.

Gödel's First Incompleteness Theorem. The Gödel sentence g, i.e., the fixed point to $\neg\, Pr\, x$, is neither provable nor refutable in T: $\nvdash_T g$ and $\nvdash_T \neg g$.

The theorem is provable from the Diagonalization Theorem and the following completeness and soundness assumptions for the T–axiomatization (see [30]):

$$\text{completeness} \qquad \vdash_T \varphi \;\Rightarrow\; \vdash_T Pr\ulcorner\varphi\urcorner,$$

$$\text{soundness} \qquad \vdash_T Pr\ulcorner\varphi\urcorner \;\Rightarrow\; \vdash_T \varphi.$$

Consistency of T is another metaproperty that is expressible in L, yet not provable in T itself.

Gödel's Second Incompleteness Theorem. If T is consistent, then the sentence Con_T, which expresses T:s consistency, is nonprovable in T: $\nvdash_T Con_T$.

Concerning minimal assumptions for the T–axiomatization that permit a proof of this theorem, we have the Löb derivability conditions, for which we refer to [30].

The above examples show that certain sentences can be constructed in a formal language to obtain an introspective meaning. The process of deciding truth of such sentences may, however, not only go beyond the formal theory itself (cf the second incompleteness theorem), but may not be formally describable at all.

Unlike "consistency of T", a truth property like "being true in a model of T" is not expressible in L. A possible formula $Tr\, x$ expressing this truth property should satisfy

Tarski's convention T:

$$\text{for all sentences } \varphi \text{ of } L: \qquad \vdash_T (\varphi \equiv Tr\ulcorner\varphi\urcorner),$$

whereby the meaning of a sentence φ becomes the meaning of $Tr\ulcorner\varphi\urcorner$, i.e., the truth conditions for φ; cf also Carnap [3]. Now, suppose that there is in L such a formula $Tr\, x$. Then, there is a fixed point sentence ψ to $\neg\, Tr\, x$, such that:

$$\vdash_T (\psi \equiv \neg Tr\ulcorner\psi\urcorner),$$

and Tarski's convention T on ψ would give $\vdash_T (\psi \equiv \neg\psi)$, implying T to be inconsistent.

Theorem (Tarski). If the object language L is adequate for its own syntax (satisfies the Diagonalization Theorem), then there is no definition of truth in L which satisfies Tarski's convention T. However, it is possible, in a metalanguage M to L, to define a satisfaction relation that satisfies Tarski's condition for truth in L.

The above results of Tarski [33] and Gödel indicate certain possibilities for partial introspection in formal languages. Possibilities that are necessarily partial, but extendable by external observation of an object language in a metalanguage.

Attempts with partial truth predicates, notably by Kripke [10], do not change this general character of an always proper partiality of linguistic introspection. Even though a partial truth predicate, unlike the above $\mathit{Tr}\, x$, can be expressed in a formal theory, its domain cannot.

5 *The Linguistic Complementarity*

Limitations of formal language expressibility, notably concerning interpretation, may be understood not only in terms of results such as those of Gödel and Tarski. By way of further examples, we have the Löwenheim—Skolem—Tarski theorems about the interpretational ambiguity in formal descriptions of infinities. These and similar results, which all are connected with the recursively enumerable character of the theorems of formal theories (see [13]), do support the thesis that a complementaristic condition obtains for languages in general.

The Linguistic Complementarity is the thesis that every language that can naturally be considered a language contains descriptions and interpretations that are complementary within the language. That is, as long as we stay within a language L we cannot completely describe L only in terms of its sentences. Both description and interpretation processes (both sentences and interpretation processes; both models and description processes) are needed in interaction for a full account of L. However, there may be a metalanguage, with a higher describability than that of L, allowing a complete description of L. In that case, we say that the complementarity is *transcendable.* If no such metalanguage can exist, the complementarity is *nontranscendable.*

(A transcendable complementarity may also be conceived of as a *relativistic complementarity*; see end of Section 6.)

To argue this thesis for general languages, we distinguish between on the one hand a sentence as a string of symbols, i.e., as a syntactic entity, and on the other hand the physical or biological embodiment of the sentence, i.e., its carrier, that we refer to as "sentence". A "sentence" may consist of physically imprinted configurations on a piece of paper, or of a biological DNA-molecule. A "sentence" is a materialistic carrier of properties that suffice to identify the corresponding syntactic sentence. An interpreter of a language works on at least two levels to understand the language. On a first level he pre-describes the physical or biological "sentence" as a syntactic sentence, and on a next level he interprets the sentence into a model. If on a conscious level, the model may take the form of a "real" entity, i.e., an entity that is complete with properties. A model may thus have time properties, be moving or changing, whereas a sentence is always independent of time in the sense that the corresponding "sentence" is stable, or constant, for as long as it takes to use it in the language for communication and interpretation. In a work of Pattee [25] physical assumptions for a language permitting reading and writing are explained.

Now, how can change be described by constancy? How can infinities be finitely described? The answer is that when we go from description (sentences) to that described (models), i. e., when we interpret, then we utilize undescribed, generative properties of the interpreter.

It follows that not all of reality can be described. For example, should we try to describe the interpretation process of a language in the same language, we are bound to encounter difficulties, because we obviously cannot have an interpretation process with some properties undescribed at the same time that we claim to describe those very properties. (The same holds for description processes, which by their inductive nature are nonrecursive and not completely describable.) The descriptions and interpretations that constitute a language are complementary in the sense that none of them can be completely reduced to the other within the language.

Actually, this general type of argument is involved in establishing also a formal language, where there is a fundamental distinction between a rule of inference and an axiom. A rule of inference cannot be completely formalized into axioms of the theory to which it belongs. It must retain a nature of real process. As stated by Reichenbach [27], this point was clearly understood by Russell at the time of writing *Principia Mathematica*, well before the works of Gödel and Tarski. Russell here makes a distinction between formalizable and non-formalizable parts of logic in emphasizing that inference cannot be stated in a formula of the system itself, but requires an external schema. We know today, says Reichenbach, that a correct formulation of this insight is to say that the schema belongs to the metalanguage; that the formalization of inference can be given, not in statements of the object language, but only in the metalanguage.

As we know, a language-like structure is also found in all forms of life, where DNA–strings play the role of "sentences", and where the epigenesis complex is a recursively built interpretation process (see [18]). There are reasons, in terms of complexity theory, for finding this peculiar, linguistic-like structure in the very complex phenomena of life. Namely, a complexity thesis of von Neumann (see [35], [16]), saying that for very complex systems their behaviour must be of a higher complexity degree than that of their structure. In order for such complex behaviours to protect themselves from degenerative forces, like those of viral attacks from the inside all the way to external attacks from other living organisms, the protective behaviour itself must be relatively safe. A way of accomplishing this is to have the directions of the protective behaviour on a comparatively low level of complexity, and thereby on a safer ground. Even if errors can occur also on a lower level of complexity, like DNA–errors in mitosis, they are less frequent and can be partially corrected by DNA–repair, an interesting form of self–repair (cf [14]).

However, if the genetic phenomena are to be considered linguistic in the general sense, where are the description processes? Well, an obvious answer is that the process is the natural selection process, working primarily on the phenotype and thereby selecting those mutated, or recombinated, DNA–strings that are fit.

Now, since the complexity thesis itself is derivable from the linguistic complementarity, the genetic phenomena do indeed support the linguistic complementarity for genetic languages. Actually, comparisons between the description process, in the form of a natural selection process, and the inductive description process in the epistemological case, show that in both cases a description of the description process requires a higher level language than that of the language of which the process is part (cf [19], [20]).

Furthermore, this general linguistic perspective suggests another view on languages as natural or artificial. Namely, that there is a natural phenomenon of language (like genetic languages existing in nature even before the evolution of a talking homo sapiens), which is of such an autological power that it can produce languages permitting us to objectify nature, including its phenomena of language. These produced languages are, however, the "natural" languages according to the more narrow terminology, and languages that in turn are produced by them are "artificial". As well known, also from other contexts, it is difficult to maintain a clear distinction between "natural" and "artificial", and we better classify phenomena of language in terms of their developmental history as long as that is known. Not that this recommendation is free from objections, however. After all, such a classification is a way of describing languages, and thus presupposes a language that is natural as a reference frame — where this latter naturalness may be of another kind than that involved in appeals to nature.

The notion of complementarity that is involved in the linguistic complementarity should not be confused with our daily uses of *complementarity* for the opposition of contrasting concepts. Rather, it may be looked upon as a means of understanding certain internal non-reducibility situations, where quests for such reducibility is a natural linguistic demand with openings in an external metalanguage, provided that the complementarity is transcendable. This view may perhaps be better understood by comparing the *linguistic complementarity* with Bohr's notion of complementarity in quantum physics, an area also facing problems of autology, in particular that behind observing observation processes.

6 *Comparisons with Bohr's Concept of Complementarity*

Bohr's ideas on complementarity came as a response to the questions of how to understand the early quantum physical findings. Questions like the wave and particle character of the electron, the uncertainty relations for a simultaneous measurement of position and momentum of a particle, and the problem of the nature of a particle while not being measured upon.

Bohr first used the term *complementarity* in his Como lecture in 1927 [1]. Although he was there preoccupied with an attempt at understanding the uncertainty relations in terms of complementarity, his view of the concept had a wider epistemological content than what might be suspected from the jargon that developed in talking of position and momentum as complementary properties. Folse [7; p 127] expresses this as follows:

> "The belief that Bohr designed complementarity simply as his analysis of the uncertainty principle is historically unfounded ...
>
> As Bohr understood the matter, both his new framework and Heisenberg's principle were the consequences of the quantum postulate; his was the consequence for the conceptual framework within which phenomena are described, while Heisenberg's discovery was its formal, mathematical consequence. In the mathematical formalism of classical mechanics, the two canonically conjugate parameters necessary to define the state of a system are independent of each other. However, in the quantum mechanical formalism these parameters are not independent but are linked reciprocally by the measure of discontinuity in change of state symbolized by Planck's quantum. Thus the uncertainty principle is the mathematical expression of the fact that in the quantum mechanical formalism, the classical ideal of a causal space—time mode of description made possible by defining the state of the isolated system is unattainable. This discovery then suggests either the need for accepting a new ideal for describing physical systems in the atomic domain and hence a new framework (Bohr's view), or the fact that the quantum mechanical description is 'incomplete' (Einstein's position)."

Bohr had a clear view of the role of language for the involved epistemological problem. Classical objectivity, that rests with the idea of a language with a truly universal expressibility, could no longer be upheld. He writes (see [7; p 16]):

> "As the goal of science is to augment and order our experience, every analysis of the conditions of human knowledge must rest on consideration of the character and scope of our means of communication. The basis is here, of course, the language developed for our orientation in the surroundings and for the organization of human communities."

Such a communication language, Bohr argued, can be no other than one which is adapted to our macroscopic world, and which employes the concepts of classical physics, those of space—time description and causal connection, in their construction. Compare later insights of the way we agree on deductive reasonings, and how the rules of inference then must be causal, and even checkable by a machine in order to settle disputes (cf [13]). Facing an irreducibility of certain quantum phenomena to classical physics, and the necessity of using the language of classical physics for intersubjective communication, Bohr was led to his complementaristic view. A view that essentially involves a specific concept of "phenomenon", rather than object of classical physics, as entity that could be talked of in the communication language.

Perhaps it is the concept of phenomenon that is at the core of Bohr's view of complementarity. Gradually, Bohr came to use the word "phenomenon" for the comprehension of the effects observed under given experimental conditions. Folse [7] explains the development as follows.

> "Adopting the word 'phenomenon' to refer to 'the effects observed under given experimental conditions' had a significant impact on Bohr's expression of complementarity after 1939. ...
>
> Bohr's leading idea in formulating complementarity centered on the complementarity of two modes of description, that of space—time coordination and that of the claim of causality. However, because the debate with Einstein showed the tendency to regard position observations and momentum observations as determinations of the properties of the *same* observed system (i.e., the same 'phenomenon' as Bohr used the term in the Como paper), Bohr began to emphasize that these two observational interactions are *different* phenomena and hence determine the properties of *different phenomenal objects.* Thus he eventually adopted a way of speaking which referred to the complementarity of different *phenomena* or complementary *evidence* from different observations."

Bohr suggested in many of his later writings that the view of complementarity might also be applied to certain problems in other fields, such as biology and psychology. But he did not attempt to formulate, in detail, a corresponding generalized concept of complementarity.

Lindenberg and Oppenheim [11] have suggested one such generalization of Bohr's concept of complementarity. They find this extended concept of complementarity justified in situations where an unsolvable *intra*-domain problem exists, and where an *inter*-domain resolution is to be found by a phenomenon-assignment.

By way of example from quantum physics, the problem of assigning a wave or particle property to an electron *per se* (electron as an object that can be isolated according to classical physics) is unsolvable within the domain of classical physics. This is the unsolvable intra-domain problem. Yet, if we don't remain inside the domain of classical physics but open up an inter-domain of classical and quantum conceptions, a resolution may be found. Refraining altogether from using classical concepts in quantum physics would make quantum physics unintuitable. The complementaristic resolution is a restricted use of classical conceptions (particle-like, wave-like) in quantum physics. Namely, where these conceptions are not applied to objects, like an electron *per se*, but to phenomena, like "electron investigated in a bubble chamber" or "electron investigated by a nickel crystal", each an indecomposable whole.

Concerning a more everyday use of the word "complementarity", Lindenberg and Oppenheim [11] write:

> "Many authors, applying the Principle of Complementarity to fields other than physics, have interpreted this principle to be a device for reconciliation of various irreconcilable approaches. Since we believe that Bohr's principle does not lend itself to such uses, it is worth-while to try to uncover the source of such misunderstandings."

By way of example, the mechanistic and vitalistic approach in psychology have been labeled complementary in Bohr's sense, as well as the so called paradox of freedom and providence. The argument being that when two approaches represent mutually exclusive modes of explanation, their equal validity places them in a complementary relationship to each other. However, as pointed out in [11], to claim that approaches are equally valid is to claim that one has no epistemological criteria for preferring one over the other; together, with mutual exclusiveness of approaches, equal validity establishes, in effect, an intra–domain problem. Yet, the mere label "complementarity" does not help. What is missing from the argument is the inter–domain problem and its resolution.

Again, it may be suggested that it is a shortcoming of complementarity, in its correct use, not to solve also the intra–domain problem. However, as pointed out in [11], such a conclusion would be seriously mistaken. Rather, *unsolvability* of the intra-domain problem is *crucial* for any meaningful application of the principle of complementarity.

By comparison, the linguistic complementarity for a language L expresses, in a most natural way, an intra–domain problem, namely that of describing L in the descriptive domain of L, i.e., in terms of L's own sentences. This intra–domain problem is by the linguistic complementarity unsolvable for every language L. In the case of a transcendable complementarity, we have an inter–domain resolution in terms of a description of L in an inter–domain of L and a metalanguage M. In the case of a nontranscendable complementarity, where there is no such fully resolving metalanguage, we can at most conceive of a metalanguage (like natural language) that allows an objectification of L as a phenomenon of description—interpretation processes, i.e., as a wholistic phenomenon that cannot be fully decomposed into well defined description and interpretation parts.

Thus, in a nontranscendable linguistic complementarity we find all the characteristics of a Bohr complementarity according to the Lindenberg—Oppenheim abstract characterization. However, in the transcendable case, the linguistic complementarity goes beyond Bohr's in that it allows an inter-domain resolution that does not directly involve the idea of a phenomenon. In this case of transcendability, the linguistic complementarity can eventually be looked upon as a *relativistic Bohr complementarity*: in a world that is relativized to L (where the resolving metalanguage cannot be seen), L becomes a description—interpretation phenomenon. Upon attempts at breaking into the phenomenon, only circular arguments will result whose consistency will have to be trusted. A demonstration of the consistency, by unfolding (see [17]), can only be made in the invisible metalanguage.

Various writers (cf [24]) have compared the circular situation behind Bohr's complementarity, in particular in questions of incompleteness of physical descriptions of reality (see [6], [2]), with Gödel's more thoroughly developed self-referential technique in proving the incompleteness of sufficiently complex mathematical theories. Such comparisons have been found plausible by some writers. Others find them invalid on the grounds that Gödel's results, unlike Bohr's, concern mathematical objects that do not pretend to say anything about the actual reasoning powers of homo sapiens as a biological species.

In my view, a valid comparison between Bohr's and Gödel's results cannot be made without a link that converts Gödel's mathematical results into some physical-like or biological-like law which, as all laws of natural science, has a hypothetical content, let be very small.

The linguistic complementarity provides such a link. It is an hypothesis, namely that every language satisfies the conditions of the linguistic complementarity, and thus also the language used in Bohr's reasoning about completeness and incompleteness of the quantum formalism as a description of physical reality. The connection with Gödel's results concerning formal languages is that the hypothesis gets support (cf [20]) from Gödel's results — as well as from Tarski's results that support a transcendable linguistic complementarity. This last remark is of special importance, because it points at the possibility that a conclusion of the incompleteness of a physical formalism as a description of physical reality is relativized to the actual language used for the formalization, and not an absolute result!

7 *Genetic Languages and Autolinguistic Processes*

As we have seen, the concept of language plays a certain role within the foundations of quantum physics. Within biology, however, we are beginning to see language in its general sense as a concept that is not only of foundational interest, but of interest also for the more specific developments of theoretical biology.

By way of example, consider the phenomenon of self–reproduction. Even before the genetic findings in the fifties, automata theoretical models of self–reproduction were suggested by von Neumann (see [35]). The results of Turing on universal computability played a basic role and were extended to universal constructability. A definite element of language (cf Section 3) can be seen in this early automaton model of self–reproduction. This insight was confirmed, or rather independently seen, by Watson and Crick in their findings of the genetic code and the following revelations of the genetic language.

The problem of identifying genetic languages is often guided by our understandings of formal languages, or of programming languages, with their possibilities for partial introspection. Perhaps an understanding of introspection, or self–description, is as essential for an understanding of language as an understanding of self–reproduction is for an understanding of genetics. At any rate, the comparison is suggestive for ways of identifying a genetic language. By way of example, reproduction processes that thrive in genetics as well as in automata theory can naturally be identified also in formal languages. For example (see [12]), as proof–processes. A proof–process for showing a given sentence, S, to be a theorem (or not to be one), starts out with S as argument and ends up (or does not end at all) with a proof–sequence with S as its last element, thereby showing S to be a theorem — by reproducing it in steps of production that are identified with steps of application of rules of inference (which produce new sentences from old). In this comparison, self–reproduction will correspond to a proof–process that can be applied to a sentential description of itself as process, thereby justifying itself. As with all forms of consistent self–reference, such a self–justification, or self–reproduction, must be partial.

An elaboration of such a comparison between a genetic self–reproduction and a proof–theoretic self–reference is suggested by Hofstadter in [9]. He compares a Henkin sentence, saying of itself that it is provable (cf Section 4), with a partially self–reproducing virus. That is, a virus that reproduces in a bacterium by injecting its DNA — its own description — into the bacterium, thereby having the bacterium transcribe and interpret the DNA into a new copy of the virus.

To appreciate the comparison, we first observe that a Henkin sentence, h, which by definition satisfies:

$$\vdash_T (h \equiv Pr\ulcorner h\urcorner),$$

is in fact provable, and thus true. As mentioned in Section 4, this is a corollary of a theorem of Löb. Again, it can be argued in terms of Gödel's second incompleteness theorem (see Section 4) as follows.

Suppose that $\nvdash_T h$, i.e., that h is not provable in T. Then $T\neg h$, meaning T extended with $\neg h$, must be consistent, i.e., $Con_{T\neg h}$. Thus, according to Gödel's second incompleteness theorem:

$$\nvdash_{T\neg h} Con_{T\neg h},$$

$Con_{T\neg h}$ is equivalent to $\neg Pr\ulcorner h\urcorner$, i.e., to $\neg h$ (cf the definition of h), and thus we have $\nvdash_{T\neg h} \neg h$. Obviously, this is a contradiction, because $\neg h$ is an axiom in the extended theory $T\neg h$ and hence provable in this theory. Therefore, the assumption that h is not provable in T must be false, meaning that h is in fact provable: $\vdash_T h$.

As just demonstrated, the Henkin sentence h allows a metaobserver to interpret it as truly saying that it is self-reproductive in terms of reproduction by proof. In other words, h contains sufficient information for the metaobserver actually to reproduce h upon interpretation.

By comparison, the DNA-sentence of a virus that reproduces in a bacterium contains sufficient information for the bacterium actually to reproduce it upon interpretation.

In the first case a metaobserver is needed for the interpretation, whereas in the second case the interpretation mechanism of the bacterium is sufficient.

A natural question, posed by Hofstadter, is whether h could be extended to say more of itself than just that it is provable, thereby diminishing the requirements on the metaobserver to check it out. Is there for example an "extended Henkin sentence", which not only says of itself that it is provable, but also provides an explicit description of its proof which, furthermore, really is true. The question was answered recently, in the affirmative, by Solovay [31].

However, from a more genuine linguistic perspective this way of comparing the two forms of self-reference may appear somewhat undeveloped.

Even if a Henkin sentence is extended to describe also its proof, the result is again a partial self–reference. We could ask for further properties also to be described. There is no natural end in asking for further properties to be included under the self–reference, except at a complete inclusion — which is impossible according to the linguistic complementarity. By contrast, in the genetic case we have an objectifiable complementaristic situation, where the bacterium realizes the interpretation process, relative to which the virus reproduces. These processes are here naturally given with the bacterium.

A virus that contains a DNA–sentence, instructing for self–reproduction, will obviously only reproduce as long as the sentence is properly interpreted. The particular bacterium that lends its interpretation facilities to the virus will however be destroyed by this generosity. As a whole, the bacteria survive by themselves being self–reproductive.

Again, the bacteria are only partially self–reproductive. Looking for properties relative to which the bacteria reproduce will naturally reveal the first steps of a further hierarchical structure of the whole interpreting epigenesis complex. In [18] we have suggested an "autolinguistic" model for this interpreting structure, with natural ties to an evolutionary perspective. That is, with mutations on the genotype and a natural selection working on the actually exposed phenotype.

A basic thought for the *autolinguistic* model is the following. A biological property is generally recognized as inherited or acquired. In either case the property can be identified as a biological interpretation of a biological description. These interpretation and description processes, biological as they are, can accordingly be themselves identified as biological interpretations of biological descriptions. The life processes thus suggest themselves as autonomous description—interpretation processes. In other words, as description—interpretation processes that themselves establish the relations that at a next level in the hierarchy constitute description—interpretation relations.

The autolinguistic production and maintenance of the description—interpretation relations at the various levels of the epigenesis complex may be thought of as a recursive stabilization (freezing) of those (inner) environmental relations, with respect to which the system once passed the test for fitness. The recursive organization is such that properties once found fit with respect to a particular surrounding are maintained fit — by maintaining the surrounding as a a constructed inner surrounding. This maintenance work may require further properties, recursively developed at higher levels such that essentially only the momentary top level is exposed to actual test by natural selection.

By way of example, the inner surrounding of the embryonic offspring, developing in the uterus, maintains a salinity from a time when the ancestral organisms evolved in a similar surrounding — then natural, but now constructed as a part of the epigenesis complex.

Again, at the lower genetic levels we have an inner surrounding, within the cell, of its chromosome. The chromosome can function as a genetic description only if the appropriate interpretation relation is established within the cell. This is accomplished by recursion within the cell such that, at for example the higher levels of recursion, proteins are synthesized (interpreted) from genes (description fragments of the chromosome) which regulate the synthesis (interpretation) from other parts of the description (other genes). A kind of self–reference is thus unfolded within the cell, explaining how a description can enforce interpretation relations for its own interpretation.

Actually, in the self–referential view of languages, with their linguistic complementarity, it is the partiality of the self–reference and the transcendability of the complementarity which, at each linguistic level, is traceable in the form of a next biological level in the epigenetic interpretation system.

8 *Trends*

There is a visible trend in modern systems theory towards objectifying subject—object formations, like in observing observation processes, describing description processes, inductively inferring induction processes, fragmenting fragmentation processes, etc. Such instances of autology are likely to occur within a systems theory that has a sufficiently large domain to permit objectification of phases of the systems formation, development, maintenance of identity, etc. Characteristically, such systems involve linguistic phenomena. One way of understanding this is to notice that the involved self–referential situation is indeed a phenomenon of reference, and as such linguistic.

An understanding of this trend naturally calls for linguistic relativizations. Such relativizations seem fairly recent, perhaps due to a lack of a sufficiently well developed general concept of language. Some results in this direction ([19], [20], [21]) concern the necessity, and possibility, of relativizing induction to language, as well as associated phenomena like relevance and fragmentation in theory formation.

These examples depend on a transcendability of the linguistic complementarity, i.e., on its relativistic nature. An active area of research in this connection is to see how various reduction concepts induce hierarchies of formal languages, suitable for relativizations. Initial studies are found in [15], [22]. One particularly deep problem is that of a reduction concept of such a generality that it allows comparison of concepts of complementarity (cf the reasonings in Section 6, comparing the linguistic complementarity with Bohr's).

In [25], Pattee develops a concept of complementarity for systems, based on a physical conception of language. He refers to the subject—object complementarity, which also plays a role for Bohr in his thinking of complementarity. Pattee makes the point that:

> "General systems theories cannot be expected to provide adequate models of biological, social or political systems, which obviously function through their own internal descriptions, until the epistemological problem of complementarity between subject and object is more clearly recognized".

It would seem that Pattee's notion of complementarity is of a non-transcendable type. At least, in its physical-like conception, it does not seem to raise the the idea of relativism like a transcendable linguistic complementarity does. Yet, we agree with Pattee in the importance of first recognizing the "problem of complementarity between subject and object".

Another approach towards relativism is suggested in [23], where Mugur–Schächter conceives of "view"–operators in description processes, developed from a pronounced metaphysical (rather than metamathematical) background. Perhaps these "views" can be compared with the invitation of [32] to "draw a distinction", or with the fragmentation and relevance operations of the inductive description processes of a language (cf [19], [20], [21]).

Developments of all these problems would seem to profit by an agreeable objectification of a general concept of language. I hope that the proposals of the paper may prove useful in this respect , at the same time that I am fully aware of the habitual effects of our most frequent use of language in communication, whereby we may be surprised to find that language also can be objectified, in metamathematical terms, as a most useful relativistic frame. kommunikation och relativism

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