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# Genetic Code, Text, and Scripture: Metaphors and Narration in German Molecular Biology

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## Argument

This paper examines the role of metaphors in science on the basis of a historical case study. The study explores how metaphors of "genetic information," "genetic code," and scripture representations of heredity (i.e. the metaphorical comparison of DNA with text and alphabet) entered molecular biology and reshaped experimentation during the 1950s and 1960s. Following the approach of the philosopher Hans Blumenberg, I will argue that metaphors are not merely a means of popularization or a specific kind of modeling (by building analogies) but rather are representations that can unfold an operational force of their own.

While the influence of cybernetics and information theory on molecular biology is well documented in historical analysis throughout recent years, this paper offers new insights into the metaphysical and religious resonances of textual metaphors in the life sciences. The main focus will be on developments in Germany, in particular on the work of the German biochemist Gerhard Schramm. In this historical case study the interaction between metaphors and experimental practices will be discussed. The paper analyzes different phases in the use of metaphors during the 1950s and 1960s: it will explore how the metaphors of a "genetic alphabet" or of "genetic code" (which were used with an illustrative purpose in the 1950s) developed into a new research program and eventually attained ontological status in the early 1960s. At that time Schramm's use of textual metaphors was reminiscent of nineteenth-century German natural philosophy. In this case, the metaphorical shift shows how the metaphor of a "genetic text" or a "genetic code," which were central for the emerging molecular biology, drew on older cultural traditions with all of their metaphysical and religious preoccupations.

## 1. Introduction: The debate on the epistemological role of metaphors of "genetic information" and of "genetic code" in molecular biology

Pointing out that the discourse of molecular biology and genetic engineering is based on the metaphor of the "genetic code" and notions of "genetic information" would be stating a rather obvious fact. In her history of the genetic code, which has by now become a classic in its field, Lily Kay described how the fundamental processes of life began to be represented as processes of information storage and information transfer. Besides the terms borrowed from information science, such as "code," "information," and "genetic program," it was the metaphor of a "genetic text" that found its way into

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the imagination of biologists in the 1950s and 1960s. Heredity was understood as a process of transmission of information. The secret of life was traced back to a universal "code" located in the DNA and based on an "alphabet" of four letters – the four DNA bases adenine (A), cytosine (C), thymine (T), guanine (G) (Kay 2000).

Nowadays, these representations offer a terminological repertoire that seems to have severed all ties with its metaphorical roots: "Code," "information," and even the rhetoric of a "genetic text" have become part of the discursive framework of molecular biology. Since the successful sequencing of the complete human genome, the metaphor of the "Book of Life" has become a standard reference, a set phrase in the Human Genome Project's self-representations, and one that seems to cater to the demands of the media. But to refer to the genome as a "Book of Life" is not merely a rhetorical strategy: At the dawn of the twenty-first century, the practices in molecular biology articulate this discipline as a new form of textual science. The metaphors of genetic language find their technological counterpart in the molecular "writing" practices of the recombinant DNA technologies. The molecular techniques for changing the genetic material re-define the scientist's function, providing him/her with new "creative" *author*ity. As the molecular biologist David Jackson stated as early as 1995: "To be fluent in a language, one needs to be able to *read*, to *write*, to *copy*, and to *edit* in that language. The functional equivalents of each of those aspects of fluency have now been embodied in technologies to deal with the language of DNA" (Jackson 1995, 358).

There is little doubt that the concept of information holds a paradigmatic position in the life sciences. The *epistemological relevance* of this information concept, however, has been the subject of vivid discussion within science studies and the history of science in recent years.[1] At stake are the metaphorical content and the metaphorical roots of molecular biology's terminological framework. The focus within the historical and philosophical debates about the status of the information concept in biology has been on two interconnected questions: What influence did information sciences have on the creation of concepts in molecular biology? And, is the metaphorical use of the information concept suitable for describing the facts and findings of the life sciences?

Thus, this discussion has focused not only on the questions of if and how genetic and hereditary processes may be adequately described with the vocabulary of genetic information and genetic code. Rather, these issues concern different theoretical perspectives on the role of metaphors in the scientific process in general.

The mathematical definition of the term "information" was developed in the late 1940s in the realm of communication techniques and the problems of maximizing the efficiency of message transmission. Independently of each other, the mathematicians Claude Shannon and Norbert Wiener defined information as a function of probability and connected the term information to the concept of entropy (i.e., information as

[1] See, for example, Kay 2000; Hedgecoe 1999; Lewis 1999; Rheinberger 1997; Sarkar 1997; Keller 1995; Fogle 1995; Montgomery 1991.

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negative entropy). Accordingly, the Wiener-Shannon theory defined the information content of a message as resulting from the probability of this message being chosen among a number of alternative options in a communication process. The concept of information thus provided a universal entity with a value equally independent of the context of the message and of its semantics (Shannon [1948] 1993; Weaver 1949; Wiener [1948] 1996). With the rise of cybernetics in the postwar era, a new perspective became dominant, propagating a world based on information flow.[2] With this concept, we also touch on one of the central questions of metaphoric transfer: Does the change of context, here: a passing on to other areas of knowledge, i.e., a metaphorical transfer, have an impact on the concept of information itself? And, furthermore, what kind of consequences does this metaphorical transfer have on the fields of knowledge in which the metaphorically used concept is introduced?

While the information concept as a metaphor describes a form of transmission in biology, the metaphors of a DNA text bring into play another trait of metaphorical language, namely, the aspect of illustration. These representations are, on a very basic level, clearly distinguished from an abstract concept of "information" based on information theory which would, in turn, be semantically open in its metaphorical application. The metaphors of a DNA text introduce another level: Metaphorical language here carries a certain degree of imagery – it is visual language. Its relation to the terminological appropriation of the world has long been discussed in theories of the metaphor. In addition, the metaphor of a "genetic code" and the comparison of the genome to text and alphabet remain within a long occidental tradition according to which nature and the world are seen as entities accessible through writing or encrypted as cipher. Thus, the metaphor of a "genetic text," which offers in the first instance a description of cellular mechanism as processes of reading and writing, holds strong connotations to the notion of "Scripture" which is central to the Western religious canon. The metaphor of the "Book of Nature," which as a part of Western tradition has gone through many changes, is also present in the code concept of modern life sciences.[3] What becomes obvious here is a cultural-historical dimension to the metaphors that extends far beyond the influence of cybernetics and information theory on the life sciences during the second half of the twentieth century.

[2] On the history of cybernetics, see Heims 1991; Galison 1994; Pickering 1995; Hayles 1999.

[3] The "Book of Nature" metaphor is usually traced back to St. Augustin, who had described God as author of two books: author of the Holy Script and author of the "Book of Nature." Blumenberg (1993) has explored in detail the origin of the "Book of Nature" metaphor within the context of the Christian theology and he has documented various levels of its cultural meanings: the metaphorical opposition of the two books in the origin of early modern sciences, the strategic use of the "Book of Nature" metaphor for the development of Empirism, the central role of book and text metaphors and the dialectics between nature and spirit in the German Romantic period (especially in the work of Schlegel and Novalis); and the continuation of the "Book of Nature" metaphor in twentieth-century molecular genetics (Blumenberg 1993). On the history of the "Book of Nature" metaphor, see also Nobis 1971; Rothacker 1979; Villwock 1986.

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The debate concerning the epistemologically linked metaphors of "genetic text" and "genetic information" often fails to give sufficient consideration to this discrepancy in metaphorical constellations. It may not be possible to separate clearly what has become joined in the historical process. Yet it is important to emphasize the different cultural-historical dimensions connected with the metaphors of "genetic information" and "genetic text," respectively. The former refers to the interface between information sciences and biology. The latter implies cultural implications that can be traced back to a centuries-old tradition in which script and scripture, with their religious background, are of particular relevance for the appropriation of the world.

However, the critique of the epistemological status of the information metaphor in life sciences has mainly focused on the historical influence of cybernetics and information theory on the re-adjustment of biological models and theories in the 1950s and 1960s. Lily Kay in particular has pointed out that the development of cybernetics and information theory provided an extensive discursive framework in which the turn of life sciences took place: away from the early twentieth-century discourse of "biological specificity" towards the discourse of "biological information" (Kay 2000). Kay argues that although the technical transfer of methods connected with the concept of "information" and "code" from the information sciences to the life sciences failed, these terms became very productive as metaphors. These informational representations provided new access to life phenomena, they guided laboratory practices, and moreover, they linked molecular biology with other realms of postwar technoculture shaped by the new information sciences (ibid., 326–331).

Evelyn Fox Keller, on the other hand, focuses on the semantic differences between the definition of "information" provided by information theory and the application of the concept "information" in molecular biology. She argues that "information" has been used only in its most colloquial sense in molecular biology, describing a "genetic instruction" (Keller 1995, 94–96). Sahotra Sarkar goes even further in his critique of the perspective that there was an extensive reconfiguration of the life sciences through the information concept in the mid-twentieth century. Arguing as a philosopher of science, Sarkar holds that "information" in molecular biology is "no more than a metaphor masquerading as a theoretical concept" (Sarkar 1997, 277), used in ways that are not only vague, but also misleading. Sarkar has sparked a debate on the exact definition of the information concept in molecular biology, and raised the question of whether the life sciences should let go of the information concept altogether. Over the last few years the use of the concept of information has been debated with great liveliness especially from a philosophical perspective and from the perspective of theoretical biologists. The authors involved in this debate mainly discussed whether the term "information" is necessary within biology, arguing either against the use of the concept in biology or defending its operative force.[4]

[4] See, for example, Barbieri 2003; Boniolo 2003; Segal 2003; Maynard Smith 2000; Sterelny 2000; Godfrey-Smith 2000; Sarkar 2000; Atlan and Koppel 1990.

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The emphasis in the following historical case study is on aspects that differ considerably from the critique described above. The argument made here will be twofold: First, I will point out that metaphors have been constitutive elements of the genesis of molecular biology, and could not be replaced with other non-ambiguous terms. Tracing back the power of the code metaphor in molecular biology to the rise of cybernetics in the postwar decades will only be of secondary importance. Instead, and this is the second argument, this case study of German molecular biology will show that the influence of metaphors on experimental research in the early 1960s dates back to much earlier days, even reaching back to cultural traditions and ideas of nature as a script, and resulting in far-reaching natural-philosophical speculations about the source of life.

In the following, I will analyze a chapter of the history of molecular biology in Germany in the 1950s and 1960s. The focus is on the work of Gerhard Schramm who belonged to the internationally renowned group of early German molecular biologists. Schramm started his academic career in the late 1930s at the Kaiser Wilhelm Institute for Biochemistry in Berlin-Dahlem. After the war, he was director at the newly founded Max Planck Institute for Virus Research in Tübingen. This institute soon became one of the leading centers of molecular biology in West Germany. During his scientific career, Schramm dedicated his research exclusively to the tobacco mosaic virus (TMV). Thus, Schramm worked on an experimental system that contributed substantially to the emergence of molecular biology in the mid-twentieth century.[5]

The example of Schramm's research on TMV allows one to trace different phases of the application and meaning of the metaphors "genetic information" and "genetic text" in the 1950s and early 1960s. I will first point out these metaphors in Schramm's publications of the 1950s and will then continue to describe their development in the experimental practices of the early 1960s. The examination of Schramm's writings from this period will demonstrate that the metaphor of a "genetic alphabet," as encoded in the DNA, was initially used for illustration purposes. It was then able to develop into a constitutive resource for a new research program, and it eventually gained an ontological status.

## 2. A case study from virus research

By the 1950s, the tobacco mosaic virus (TMV) had assumed the status of a model object for the life sciences. Not only is the history of this plant pathogen virus closely linked with the emergence of virology as an independent discipline; it also

[5] On the history of virus research in Berlin-Dahlem and Tübingen respectively during the "Third Reich" and the early 1950s, see Macrakis 1993, 110–125; Deichmann 1995, 148–152; Rheinberger 2000; Brandt 2004, 55–103; Lewis 2004; Gausemeier 2005, 221–254.

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holds an important position in the development of molecular biology.[6] In the 1930s, Wendell M. Stanley, then at Princeton's Rockefeller Institute, represented the virus in crystalline form (Stanley 1935). These findings, in retrospect often regarded as the symbolic birth of molecular biology (Kay 1986; Morange 1998), had an enormous impact on the new perspective of fundamental life processes. Stanley's crystallization of the virus demonstrated that an entity with the basic characteristics of a life form – e.g., the ability to self-reproduce – could be represented as a macromolecule. In years that followed, TMV, on the threshold between alive and lifeless, turned into a model that gave a new spin not only to virology. Angela Creager has recently shown how TMV became the favorite experimental research subject of biochemistry, biophysics, and genetics. The entire repertoire of experimental techniques that shaped the space of experimental representations in early molecular biology were applied to TMV, including ultracentrifuge analysis, electrophoresis, electron microscopy, and X-ray crystallography. Thus, experimental research acquired a dynamic which soon turned TMV into one of the most extensively researched nucleoproteins in the 1940s. It became a model object serving as a representative for research into molecular relations in self-reproducing entities – which means that it was also representative for the still undiscovered genetic structure (see Creager 2002).

TMV research kept pace with developments in molecular biology throughout the 1950s. In the early 1950s, it was known that the virus consisted of two components: a smaller RNA part and a much larger protein part, which was assumed to consist of a number of identical sub-units. Starting in 1953, Schramm's lab in Tübingen worked on the amino acid sequencing of these TMV protein sub-units. After extensive efforts, this work finally led to the clarification of the virus's entire amino acid sequence in 1960 (Anderer et al. 1960). During their research on the virus structure, Schramm's group developed a gentle method of separating the RNA from the virus. In 1956, Schramm and the physicist Alfred Gierer were able to demonstrate that the isolated RNA was infectious in itself, proving to be "that component of the TMV that causes the process of reproduction alone," and could therefore be considered "the carrier of genetic specificity" (Gierer and Schramm 1956a, 142; Gierer and Schramm 1956b). Only a few weeks earlier, Heinz Fraenkel-Conrat and Beatrix Singer, both working at Stanley's virus lab at Berkeley, had published their finding that the TMV's RNA component alone could be infectious (Fraenkel-Conrat 1956; see also Creager 2002, 266–316).

These results from Tübingen and Berkeley met with great enthusiasm from molecular biologists. They also added considerably to Tübingen's reputation as one of the centers of molecular biology in Germany. The results of the TMV system coincided with the growing acceptance of the notion that genetic material was identical

[6] On the history of the research on the tobacco mosaic virus since the end of the nineteenth century and the role the virus had in the history of virology and molecular biology, see van Helvoort 1991; Scholthof et al. 1999; Harrison and Wilson 1999; Creager 2002.

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with DNA. Alfred Hershey and Martha Chase's experiments on bacteriophage had demonstrated as early as 1952 that DNA could be considered to be the genetic material (Hershey and Chase 1952). Yet, as far as the ribonucleic acids were concerned, the situation was a little more complicated. Their role within protein metabolism was the subject of vivid discussions, but at that time their specific effects were still unknown. Moreover, the structures of different ribonucleic acids were not yet clear, unlike that of DNA. The results obtained from the TMV system served to demonstrate the possibility of generalizing the functional characteristics of the nucleic acids in general. For the first time, experiments delivered clear results proving RNA to be the carrier of genetic specificity – and for some scientists, this meant: the carrier of "genetic information." A small circle of scientists surrounding the astrophysicist George Gamow and the Cambridge molecular biologist Francis Crick was at that time developing new conceptions of the processes of heredity and protein synthesis, using the terminology of "molecular coding" and "information transfer." Gamow was the first to introduce a cryptographical approach to the so-called "coding problem," and this soon stimulated other scientists, like James Watson, Francis Crick, his Cambridge colleague Seymour Benzer, and the Caltech molecular biologist Max Delbrück to discuss various theoretical coding schemes in the mid 1950s.[7] To these scientists the results gained from TMV were a strong support of their own thesis that during protein synthesis, "information" was being "transmitted" from the DNA to the protein via RNA, as Crick phrased it in a well known article in 1958. In this article, he coined the so-called "Central Dogma" of molecular biology that states a one-way transfer of information from nucleic acids to proteins (Crick 1958).

## 3. "Information" as supplement

In the context of the above-mentioned experiments on the structure of TMV in the mid-1950s, the notion of information also entered Schramm's records. The term "information" first appeared in a lecture he gave in the summer of 1955 (see fig. 1).

In a passage referring to Hershey and Chase's work on the bacteriophage, we find the following note added by hand: "For the [transmission?] of hereditary characteristics – DNA solely responsible, Cipher [*Geheimschrift*], instructions determined." In the following sentence, the term "functions" has been crossed out and replaced by the term "information." It now reads: "Several 100 informations which are decisive for

[7] This history of the coding concept in the 1950s is well known: In 1953 James Watson and Francis Crick suggested that "the precise sequence of the bases (in DNA, C.B.) is the code which carries the genetical information" (Watson and Crick 1953, 965). Inspired by the Watson/Crick model the physicist George Gamow introduced a first coding scheme (Gamow 1954; Gamow 1955) that stimulated vivid discussion among some information scientists and some molecular biologists. Lily Kay has analyzed this "formalistic phase" of coding discussions during the 1950s in detail, tracing them back to cybernetic discourse (Kay 2000, 73–192).

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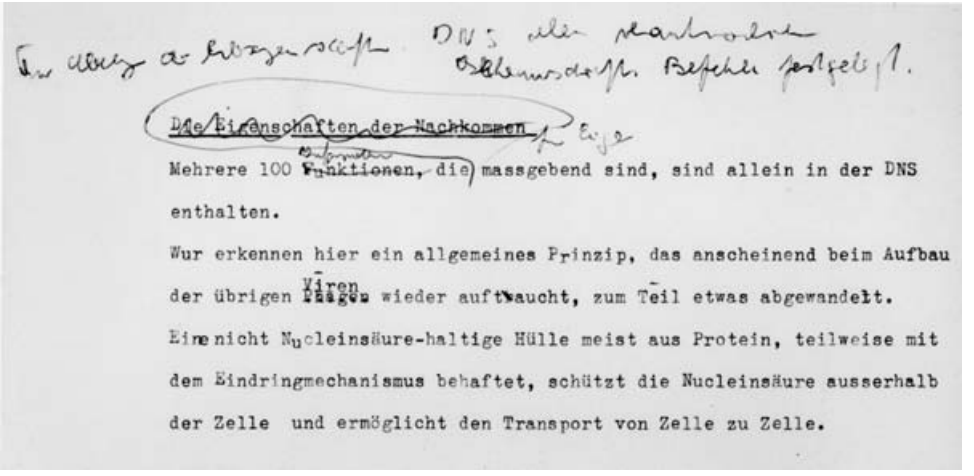

Die Eigenschaften der Nachkommen
Mehrere 100 Funktionen, die massgebend sind, sind allein in der DNS
enthalten.
Wir erkennen hier ein allgemeines Prinzip, das anscheinend beim Aufbau
der übrigen Viren wieder auftaucht, zum Teil etwas abgewandelt.
Eine nicht Nucleinsäure-haltige Hülle meist aus Protein, teilweise mit
dem Eindringmechanismus behaftet, schützt die Nucleinsäure ausserhalb
der Zelle und ermöglicht den Transport von Zelle zu Zelle.

**Fig. 1.** Text passage from an unpublished manuscript. A lecture Schramm gave in 1955 with the title: "Shape and Structure of Viruses," Archive for the History of the Max Planck Society, Berlin, Abt. III, Rep. 62, Nr. 47.

the characteristics of the offspring are contained in the DNA alone" (Schramm 1955, 5; translation C.B.)

What this text shows us are the first traces of a terminological displacement. The word "information," far from obtaining a more specific meaning, first replaces the well-established term "function." Exposing as it does the complementary character of the concept of information, the text passage serves as an example for the early use of this terminology in biochemistry. The role occupied by the concept of information at this point differs clearly from its status in the theoretical speculations of the same period by Gamow and Crick, concerning a "genetic code." Whereas in their theoretical debate, the information concept achieved the rank of a new entity in the life sciences, ranking on the same level as concepts of energy transmission and metabolic processes, it was only of marginal importance in biochemical research. "Information," as is demonstrated by the passage from Schramm's lecture cited above, seemed at first to be merely a catchphrase – a fad word, with an undefined and exchangeable meaning.

It is, however, a different matter with the metaphors of (encrypted) "code" and "genetic text." In January 1956, Schramm gave a lecture entitled "The Meaning of Science for Contemporary Man," as part of a lecture series at the University of Tübingen dedicated to "Life as a Subject of Biological Research." Schramm's lecture focused on Watson and Crick's model of the DNA double helix published three years earlier. Schramm described the structure and function of nucleic acids as follows:

> These are molecules with a chain structure. The types of chain links are the same for all organisms. We always find only four different types, which can be imagined as four kinds

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> of pearls of different colors and shapes. These are then used to build chains of different length and with differing sequences of pearls. The difference in the hereditary substance of a virus, a unicellular organism, a violet, an elephant, and a human being does merely consist in the sequence and quantity of these four pearls. Yet calculations have been made to the result that [despite?] this limited numbers of signs (namely, four), an alphabet may be created with which the entire vast [variety] of life forms may be expressed. (Keep in mind that the Morse alphabet consists of only two signs: – •, and could nevertheless be used to express almost every word in the world.) Thus, instructions are transmitted in the nucleic acids, instructions according to which the structure of the offspring is built in the same way as that of the ancestor.[8]

This quotation shows that the metaphors of alphabet and signs initially served merely to illustrate the scientific findings. Applied as illustrations, the metaphors simultaneously expressed the fascination with the effect of the nucleic acid, that "wonder" of nature, as Schramm put it, which was only beginning to reveal its shape to scientists (Schramm 1956a, 10). While the concept of information assumed only a marginal status in Schramm's texts of this period, the metaphors of molecular signs and alphabet held a tremendous fascination for him. The historiographic discussion, focusing on the use of "information" in life sciences and the reciprocal relations between molecular biology and the information sciences connected with it, has failed to consider one particular aspect of the genesis of the terminological apparatus of molecular biology which we now seem to be touching on: Namely, that in science as anywhere else, the attraction of metaphors consists in their power to make things and complex facts visible. Or, as Ludwik Fleck once explained the function of illustrations in science:

> The achievement of vividness in any knowledge . . . has a special inherent effect. A pictorial quality is introduced by an expert who wants to render an idea intelligible to others . . . . But what was initially a means to an end acquires the significance of a cognitive end. The image prevails over the specific proofs and often returns to the expert in this new role. (Fleck [1935] 1979, 117)

The circles Fleck described could also apply to the role of metaphors as a special case of imagery or of graphic knowledge. From Schramm's notes we may gather that until the late 1950s, he was neither concerned with theoretical deliberations on the so-called coding problem in any further detail, nor did possible connections with information science seem important to him. This was probably also the case for other contemporary biologists or biochemists. However, the metaphor of a "molecular alphabet" or "genetic text" did play an important role in the 1950s. This metaphor filled the gaps in the precise understanding of the much-discussed mechanisms of protein biosynthesis. In

[8] Gerhard Schramm, unpublished handwritten manuscript, "Ringvorlesung," probably January 1956, University Tübingen, quotation on pages 10–11, translation: C.B., in brackets: my emendation of illegible words, Archive of the Max Planck Society, Abt. III, Rep. 62, Nr. 119.

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a lecture probably written in 1956, Schramm explains his work on the sequencing of amino acids in the TMV protein sub-units:

> Model research has shown that the reproduction of the protein is carried out with extraordinary precision. Number, type, and sequence of the amino acids are all clearly determined and strictly adhered to in reproduction. *This mechanism strongly suggests a comparison with a printing press producing the ever-same printed sentences over and over.* And research indeed has shown that a similar process is taking place in the cell. The part of the template is taken over by the RNA, directly or indirectly. Virus research does now offer us the unique opportunity to support these rather *abstract* notions with *hard chemical* facts. In a cell, it is hard to determine which template is creating which prints. With plant viruses, however, we have a specific RNA and a specific protein, and they must somehow be in a *relation of template and print*. A detailed analysis of the protein as well as the nucleic acid should allow us to determine this relation more specifically and to thus support the entire structure we have so far developed. We chose the TMV as most suitable subject for this research .... The TMV *allows us, so to speak, to read the print and to decipher the individual letters*.[9]

Holding nucleic acids in the form of a molecular 'template' to be involved in the creation of proteins and thus responsible for their particular structures, was not then a new notion. Since the late 1940s, the assumption that the synthesis of proteins required some form of molecular pattern had increasingly gained acceptance. These conceptions of templates replaced the so-called multi-enzyme-theory of protein synthesis (Morange 1998, 126–132; Rheinberger 1997, 130–132). In the mid-1950s, the template notion, borrowed from printing technology and in itself rather static, was now given a new turn by the introduction of the metaphor of 'molecular writing'. This results in a representation referring to the printing of books and letters. Here as before, the transmission of 'information' in protein synthesis is not described as a dynamic process. Moreover, the quote demonstrates that at this point in time, the relation between the figurative language and its significate had already been reversed. Comparisons with letters and textuality no longer served to illustrate the experimental subject. Rather, they "acquire[d] the significance of a cognitive end" (Fleck [1935] 1979, 117). They now offered "abstract notions" which were supported by "hard chemical facts," as Schramm put it.

## 4. The "genetic code" as a subject of experimental research

The scientists' hope "to be able to read the [protein] print and to decipher the individual letters" (Schramm 1956b, 10), and to arrive at more specific evidence concerning the

[9] Gerhard Schramm, unpublished manuscript, "Biochemische Probleme der Pflanzenvirusforschung," pages 9–10, without date, probably 1956 (translation and emphasis C.B.). Archive of the Max Planck Society, Abt. III, Rep. 62, Nr. 99.

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structural relations between nucleic acids and protein, remained unfulfilled in the mid-1950s. Some years would pass before the tobacco mosaic virus became "the Rosetta stone of biochemical genetics" (Broda 1959, 244). However, near the end of that decade, a number of experimental incidents happened that gave the TMV system the potential to suddenly throw light on the correlation between nucleotides and amino acids. Thus, the TMV system entered the sphere of what, in the theoretical approaches of the 1950s, had been discussed as the "coding problem." Several things had already enabled this development to take place: In 1958, a publication by Schramm and his coworker Heinz Schuster pointed out that treating TMV with nitrous acid disabled the virus (Schuster and Schramm 1958). Nitrous acid caused a specific transformation of bases in the RNA. Schuster and Schramm were able to demonstrate that the transformation of a single one of the estimated 6,000 nucleotides in the virus sufficed to eliminate the infectious effect of the TMV. Only a month later, in August of 1958, Karl-Wolfgang Mundry and Alfred Gierer published their results showing that nitrous acid could also cause mutations in TMV (Mundry and Gierer 1958; Gierer and Mundry 1958). In combination with the techniques of amino acid analysis, this possibility of creating controlled mutants by chemically altering the RNA of the virus provided an experimental strategy that could be followed to examine the type of relations between the RNA's nucleotides and the sequence of the amino acids in the protein. After treating the virus with nitrous acid, thus causing alterations of nucleotides, the scientists had to observe the effect of these alterations on the amino acid composition of the protein sub-units. In the end, it was Heinz-Günter Wittmann, doing research at the neighboring Max Planck Institute for Biology in Tübingen, who combined these experimental steps and started a series of comparative analyses of the amino acid composition of TMV mutants in 1959. Until the early 1960s (from 1961 on in cooperation with Brigitte Wittmann-Liebold), Wittmann studied several hundred TMV mutants, examining the type of resulting amino acid replacements in the protein (Wittmann 1959; Wittmann 1963a; Wittmann 1963b).

As I have described in more detail elsewhere,[10] this research on the TMV system around 1960 was an early, if not the first, promising attempt to decipher the genetic code, which until then had only been a subject of speculation and theoretical work. Although the TMV system was recognized at that time as a likely avenue for solving the coding problem, the research did not lead to the rapid breakthrough scientists hoped for. As is well known, the "deciphering" of the "genetic code" was eventually achieved by other means. At the 1961 Congress on Biochemistry in Moscow, Marshall Nirenberg of the National Institutes of Health in Bethesda declared that he, together with Heinrich Matthaei, had successfully synthesized defined polypeptides using synthetic polyribonucleotides of known composition (Nirenberg and Matthaei 1961). The first so-called "code word" was considered to be deciphered. In the years that followed,

[10] Brandt 2004; on the research on TMV and the genetic code in Stanley's lab in Berkeley, see Creager 2002, 303–316; Kay 2000, 179–192.

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these results triggered a veritable run on the deciphering of further base triplets, in which a number of laboratories all around the world took part until 1966, when the scientific community finally celebrated the clarification of the entire genetic code (see Kay 2000, 235–293).

## 5. Scripture and the origin of life: "Genetic code" on the crossroads between ideal concept and information

The beginning of biochemists' preoccupation with the so-called "coding problem" in the early 1960s marks a clear break.[11] Lily Kay has described this biochemical phase as a turning point in the history of the genetic code (Kay 2000, 235–293). It was not only that the biochemical approach had turned the notion of a genetic code into an experimental object. It was also that a development began, which appears to be an integral part of the processes by which scientific discourses and practices can be converted by metaphors, namely that they are taken literally. The metaphor of "genetic alphabet," introduced in the 1950s for merely illustrative purposes, was now being examined for its literal content: Schramm said in an interview on "What Is Life?" that the essence of the process of heredity was the transmission of "blueprints" which the operating molecules read and realized. Biochemistry, he continued, had shown that this notion of molecular reading was "almost literally true."[12] And in a lecture draft written in 1962, he explained:

> The genes consist of long molecular chains, which we chemically designate as DNA. According to the results of molecular biology, the blueprints in these gigantic molecules are in fact deposited in the form of writing [*Schrift*]. It contains a kind of encrypted writing or code [*Geheimschrift oder Code*], which has been mostly, but not yet completely, deciphered. Biochemistry succeeded in discovering how this script [*Schrift*] is multiplied and transmitted to the offspring. Biochemistry also demonstrated how this script [*Schrift*] is read by other molecules and how its meaning [*geistiger Gehalt*] is turned into practical reality. *The astonishing thing is that we have in fact discovered writing [Schrift] in these relatively simple molecules, when we had so far believed that the invention and the reading of scripts [Schriften] was possible only to humans*. (Schramm 1962a, 3; translation and emphasis C.B.)

As this passage clearly shows, Schramm was astonished by the fact that the notion of "molecular writing" could be perceived not only as a descriptive model. He shared his astonishment with many of his colleagues. Soon, a discussion began on the reach of

[11] Around 1960 there were at least three main experimental approaches for solving the genetic code: besides the already mentioned biochemical work of Nirenberg and Matthaei, and the research on TMV that was done in Tübingen and Berkeley, there was a genetical approach in Cambridge, where Crick and Brenner worked with bacteriophage and studied the effect of different mutagens. This research led to settle that the genetic code consisted of "three-letter" codons in 1961 (see Chadarevian 2002, 186–198).

[12] Interview on "What is Life?" without date, probably early 1960s, Archive of the Max-Planck Society, Abt. III, Rep. 62, Nr. 108.

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analogies between the language of the genes and human language. For this debate, the linguist Roman Jakobson turned out to be highly influential. He initiated a number of meetings that explored possible links between genetics and linguistics. In August 1962, Schramm was present at one of the first of these meetings, organized by the Massachusetts Institute of Technology (MIT). A small circle of biochemists, biophysicists, and information scientists gathered to discuss possible parallels between the principles of the genetic code and linguistic criteria for human language (Kay 2000, 297–307).

This colloquium certainly reinforced Schramm's evaluation of analogies between writing and language to be more than simple means of circumscription. Yet, the far reaching implications of the writing and scripture metaphors had a higher influence on Schramm than the attempts to grasp the relations between bases and amino acids from a linguistic perspective. His fascination with the similarity he perceived between DNA and text – as writing and scripture – was at once stimulus for and reflex of a newly emerging research interest.

In the early 1960s, Schramm started to work on biochemical nucleic acid synthesis, a research area that was highly relevant for the coding problem at that time. In the wake of Nirenberg and Matthaei's results, the most direct route toward a complete exploration of the genetic code seemed to be via the creation of short polyribonucleotide chains which were then inserted into the cell-free E. coli system, with the goal of determining the polypeptides that were built with this "input." Schramm, too, tried to bring the biochemical synthesis of polyribonucleotides that he had developed to bear on the problem of the genetic code. Yet this was merely a side step in his research. The main aim of his approach lay elsewhere: Until his early death in 1969, Schramm tried to develop a new experimental system based on the chemical ribonucleotide synthesis. This system was to provide a model for studying the pre-biological origin of self-duplicating systems, i.e. of living organisms. This means that Schramm was trying to chemically create long-chained polyribonucleotides from their single elements, under conditions similar to those of an early geological stage on earth. Thus, he wanted to explain the emergence of "informational" macromolecules (Schramm et al. 1962; Schramm 1965b). These biochemical attempts to grasp the origins of life were strongly influenced by metaphors of genetic writing or text: The dichotomy of mind and matter implied in the notion of text and writing became one of the driving forces in this new experimental field of representation.

The notion that nucleic acids carry "the blueprints in fact . . . in the form of writing" (Schramm 1962a, 3), led Schramm to view "information" as something referring to an "ideal concept" present in nature. "Information," as Schramm explained in an abstract of his new experimental approach,

> represents an ideal/spiritual concept [*geistiges Konzept*] that is supported by material phenomena. But it has as much and as little to do with the matter in which it is stored and in which it will be reproduced as the intellectual content of a book has with

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> the letters in which it is printed. Biochemical research today is already concerned with the problem of how this ideal/spiritual concept [*geistiges Konzept*] of life originated, that is, how nucleic acids could emerge in nature and how it is possible that they contain meaningful information. (Schramm 1962b; translation C.B.)

What is at stake here implies more than the simple alphabet analogies which Schramm repeatedly emphasized when he explained the problem of the origin of life. Schramm's representations were based on the connotations supplied by the metaphors of scripture and the "Book of Nature." The concept of Holy Scripture pervades the whole of Western cultural history: as the Book of Books and the manifestation of a totality, as prescription or law, as message, or as the revelation of a divine plan. And as Blumenberg pointed out, even the term "evolution" refers to the textual semantic field. The etymological root of the word "evolutio" refers to "unrolling a scroll" (Blumenberg [1981] 1993, 19). The images Schramm used to present his new experimental approach echo the narrative patterns of biblical myths of world creation. Thus, in a lecture held for the Jungius Society in Hamburg, he stressed in 1962:

> As I have pointed out to you at the beginning, the key element in the origin of life is not matter, but its informational content, i.e. the blueprint of life. In the beginning was the word (Logos!), the meaningful plan, yet even this plan has a history of origins, albeit one that is hard to understand. To disentangle this jumble of thoughts, we can proceed as follows: We have first searched for and found a method to link nucleotides arbitrarily and without determined meaning. Then we searched for ways to influence this arbitrary polymerization, bestowing meaning upon it. (Schramm 1962c, 8–9; translation C.B.)

Evolution is here being constituted as a revelation, a process that unfolds a quasi-divine meaning or an all-encompassing spirit. This narrative pattern outlined by the metaphor of a genetic text soon became a driving motivation for experimental research, providing a speculative framework. Schramm's notion of "information" as an "ideal/spiritual concept" [*geistiges Konzept*] reproduced a dichotomy giving the immaterial privilege over the corporeal, describing the latter as a merely supplementary phenomenon. This priority of the spiritual over the material lay at the heart of Schramm's understanding of the origin of life. Whenever he talked of the "development of ever more highly refined and meaningful [*geistvollere*] information" (Schramm 1962a, 10; translation C.B.) in the process of evolution, or when he described molecular evolution as a development "towards ever higher perfection" (Schramm 1963b, 95; translation C.B.), he not only reproduced the original narrative of a spiritual concept finding its manifestation in matter. This implicit narrative with its vague outlines also filled the gaps that Schramm's experimental research with its chemical approach had to leave open. Explaining the origin and evolution of biological information would have required an elaborate mathematical theory that Schramm's approach – grounded as it was in chemistry – did not offer.

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The dynamics that unfolded from the metaphors of genetic text and genetic information in the early 1960s are best described by Hans Blumenberg's theory of metaphor. In his "Paradigms of Metaphorology," Blumenberg stressed the autonomy of metaphoric language which characteristically can not be translated into clearly defined terminological meaning. Rather, as Blumenberg claimed, it presents "a catalytic sphere, which constantly enriches the terminological world without ever using up its founding base" (Blumenberg 1960, 10; translation C.B.). Metaphors in the sphere of science are thus not secondary, deducted, transmitted and in this sense: non-proper means of expression, which may be said to serve as stopgaps for a little while. They form, on the contrary, a constitutive element in the origin and development of scientific models and theories. According to Blumenberg, they not only precede the coining of a terminology, but, due to their metaphoric vagueness, they provide a productive influence on the dynamics of scientific developments (Blumenberg 1979, 75–93).

This movement, bearing more similarity to a permanent displacement of meaning than to a definition and fixing of terminologies, can also be traced in Schramm's texts. From 1963 until 1965, Schramm held a series of lectures entitled "Idea and Matter in Modern Biology," which can be seen as an attempt to furnish his research with a philosophical framework.

The lecture manuscripts prove the biochemist's strong effort to give deeper meaning to the term "information." The metaphor of "genetic information," which in the mid-1950s was still only of marginal importance for Schramm's research, had now moved to the center of his quest for a terminology suitable for the new findings in biology: Schramm now also paid close attention to the concepts of information theory. He connected the formal definition of the information concept as it was developed in information theory (i.e. its definition as the quantitative measure of the probability of a message and its independence from the medium of transport) with the notion of an immaterial, quasi-"spiritual" entity. Its mathematical precision made the term "information" "acceptable for mathematically oriented scientists," Schramm explained in 1963. "On the other hand, it could also satisfy those scholars in the humanities who until now have missed ideal values in biology. We do thus have a promising point of departure for a terminology that is adequate for biology" (Schramm 1963a, 8, translation C.B.). That Schramm tried to posit molecular biology at the crossroads of natural sciences and the humanities is not the only surprising fact here. The references to an idealistic natural philosophy that he derived from the information concept may be read as a specifically German version of the discourse on information in the life sciences. As Schramm emphasized:

> Without hesitation, the description of the molecular processes uses terms such as writing, "selection," language of the proteins, etc., all of which are taken from the sphere of intellectual human activity. This shows us that what is at stake here is something referring to a spiritual [*geistige*] world, something transcendental, something that is placed higher than matter. (Schramm 1963a, 7; translation C.B.)

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While the international literature of molecular biology in the 1960s was concerned mainly with the relations between molecular biology and cybernetics, and while the terms "genetic information" and "genetic program" became synonymous,[13] Schramm used philosophical categories to explain the notion of "genetic information" in the life sciences. This transition to an ontological use of the information concept is certainly not generalizable to all of German molecular biology at that time (although Schramm was one of the most famous molecular biologists in Germany and his research was widely received at that time). Nevertheless, we find here a particular German case that points to the influence of specific cultural traditions. Schramm's writings illustrate how the power of textual metaphors took hold of a way of thinking that turned more and more towards philosophical questions. The way Schramm used the information concept to deal with longstanding questions concerning the essence of life became more and more reminiscent to parts of Romantic natural philosophy.[14] The idea of a 'spiritual concept' [*geistiges Konzept*] in nature led Schramm to consider a form of original evolutionary semantics [*Uridee*],[15] an idea which in turn allowed him the associative connection with Plato's concept of an original idea:

> With regard to animate nature Plato's theory of ideas proves amazingly appropriate, if we consider genetic information to be an idea. It is obvious that the idea of how to build a particular plant or animal, represents the only enduring thing [*das einzig Bleibende*] over the course of generations. This idea is in fact the only "being" [*einzig Seiende*] whereas the bodies, in which the prototypes [*Urbilder*] are reflected, change and pass away. In much the same way as the ideas, the genetic information is immaterial but nevertheless real. (Schramm 1963a, 8; translation C.B.)

With his references to Plato's theory of ideas, Schramm embeds his texts within the tradition of natural philosophy and idealism. This, of course, is a surprising turn in the history of molecular biology, whose main characteristics are usually assumed to consist of a reduction of biological phenomena to the explanations of physics and chemistry. In the early 1960s, as molecular biology began to ascertain itself as an institutional discipline, Schramm emphasized the special position of biology within the natural sciences. "If I tried to fit these thoughts in with the intellectual currents of our time," he finally explained in 1965, "I should say that materialism, carried to its final consequence, has to lead to idealism" (Schramm 1965a, 16, translation C.B.).

[13] On the history of the metaphor of a "genetic program," see Keller 2000, 73–101.

[14] As Robert Richards has recently argued, main characteristics of early nineteenth-century German *Naturphilosophie* were a theory of archetypes and a metaphysical position, "in which matter and *Geist* (understood indifferently as mind or spirit) were regarded as two features of the same underlying *Urstoff*, the causal activities of either had ultimately to express a unified force" (Richards 2002, 10). On the history of natural philosophy, see also Böhme 1989.

[15] Schramm 1963a, 11, the German quotation related to this aspect is the following: "Die unbestreitbare Tatsache der Evolution zwingt uns zu der Annahme, dass der Informationsgehalt der Lebewesen zu Beginn einfach war und dann immer komplizierter wurde. Dies führt logischerweise zu der Frage nach einer Uridee, aus der sich das Leben entwickeln konnte."

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## Conclusion

As the historical exposition has shown, the metaphors of text and information went through different phases. Schramm's writings serve as examples for this process, pointing out that in the course of the 1950s and 60s, the metaphors of "molecular writing" and "information," originally adopted for merely illustrative purposes, became central and fundamental terms in molecular biology. This study has demonstrated that the metaphor of "molecular text" in particular gave cause to extensive speculations in the early 1960s. The connections and references established by Schramm during this period prove that the genesis of the conception of information in the life sciences was caused not solely by the rising success of information sciences. The metaphors of text and writing used in molecular biology are the continuation of an element of Western cultural tradition: i.e., the notion of the "Book of Nature," which since the mid-twentieth century has developed into that of a "Book of Life." Schramm's case, as part of the history of German molecular biology, has served to demonstrate that the metaphors of a genetic text functioned not only as mere rhetoric, but also need to be regarded as one of the driving resources for the development of knowledge in molecular biology.

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