

Hopeful Heretic – Richard Goldschmidt’s Genetic Metaphors

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ABSTRACT – Richard Goldschmidt famously rejected the notion of atomic and corpuscular genes, arranged on the chromosome like beads-on-a-string. I provide an exegesis of Goldschmidt’s intuition by analyzing his repeated and extensive use of metaphorical language and analogies in his attempts to convey his notion of the nature of the genetic material and specifically the significance of chromosomal pattern. The paper concentrates on Goldschmidt’s use of metaphors in publications spanning 1940-1955.

KEYWORDS – Analogical models, gene action, systemic mutation, genetic hierarchy

Introduction

Richard Goldschmidt is one of the well-known “heretics” of modern genetics and evolutionary theory. Though his views on evolution have been gaining renewed interest for some time, it is generally accepted that his views about the material basis of genetics – his “theory of the gene” to use the terminology of the field – were simply wrong. At a period in which most attention was directed to transmission genetics, Goldschmidt’s emphasis was on *physiological genetics*, or the developmental functionality of the genetic material. His non-traditional ideas concerning the nature of genes, which he began publishing around 1938, centered on the rejection of the notion of atomic, corpuscular, and independent genes, arranged on the chromosome like beads-on-a-string (Allen 1974; Dietrich 1995). His primary arguments in favor of this view were based on the results of research on position effects and mutagenic effects such as X-ray radiation and temperature shocks as well as his research on spontaneous mutability (Goldschmidt 1938b, 311-313; 1937a,b), but he also supported his theory of the gene on the basis of his evolutionary argument which emphasized the evolutionary role of chromosomal pattern changes. If chromosomal rearrangements

produce evolutionary results, Goldschmidt argued, the conclusion must be that chromosomal patterns have genetic effects (Goldschmidt 1940, 199-203).

Goldschmidt likened the classical theory of the gene to the individual atom of old physics and argued that genetics in 1940 was in a state akin to that of physics immediately before Rutherford (quoted in Carlson 1966, 126). According to his view, the eventual model, once the Rutherford stage is reached and genetics is ready for its own Planck and Bohr, will be a model of the chromosome and not of individual particulate genes.

The aim of this paper is not to rehash these well-studied debates (Carlson 1966 ch. 15; Allen 1974; Dietrich 1995; 2000a,b; 2008; Richmond & Dietrich 2002) but rather to provide an exegesis of Goldschmidt's intuition as portrayed through his repeated and extensive use of metaphorical language and analogies in his attempts to convey his notion of the genic action of chromosomes (i.e., action of genes) to his scientific milieu.¹ For these purposes metaphors *sensu stricto*, similes, and visualizations that are meant to aid understanding, are more similar than different and all are discussed here under the general term of the metaphor. While also used for rhetorical purposes, as illustrated below, my main focus is on Goldschmidt's use of metaphors as analogical models (cf. Hesse 1963) of his ideas on the nature of genes and their possible evolutionary significance. While Goldschmidt used metaphors throughout his scientific career (for examples drawn from his early work see Allen 1974; Richmond & Dietrich 2002), in this paper the discussion is restricted to Goldschmidt's use of metaphors in the later part of his career in arguments against the notion of a particulate gene. A discussion of metaphors pertaining to the gene used by other researchers at the time can be found in Keller's work (Keller 2002).

It might be argued that the plight of the original thinker is to articulate intuitions in such a way that they are understood and hopefully accepted by the community. The burden for acceptance becomes harder the more original the ideas are but also depends crucially on the degree to which the intuition has matured, as well as on the conceptual tools available for articulating ideas of the general type the thinker is trying to make (to himself as well as to others). These conceptual tools may come from within the discipline, from other scientific or mathematical disciplines, as well as from common usage. Richard Goldschmidt's metaphors were mainly drawn from this last reservoir.

I work from the premise that identifying and concentrating on

¹ I mostly follow Goldschmidt's use of the term "genic action." I use the term "genetic action" mostly to refer to more general genetic effects.

metaphors introduced by a scientist, in discussions that otherwise would employ the standard scientific terminology in the field, assists in identifying the core innovation – as seen by the scientist himself – and is thus a useful interpretive tool. Specifically, I argue that throughout his discussions of evolution – that is, his well known arguments for a sharp distinction between the events leading to micro-evolution and the events leading to macro-evolution – the theory of the gene concerned Goldschmidt the most and, indeed, was what he was at most pains to articulate, suggesting that he felt his theory of the gene was a major barrier for understanding his ideas.²

To explore these ideas I will concentrate solely on Goldschmidt's metaphorical accounts of the nature of genes and chromosomal structure (the two go hand-in-hand, as we will see) and, in the interest of length and focus, commit the interpretive sin of decontextualizing this discussion (for more on the historical context, see Carlson 1966, ch. 15; Dietrich 2000b; 2008).

I will discuss Goldschmidt's metaphors for genic action in publications spanning 1940-1955, beginning with *The Material Basis of Evolution* (1940), concentrating on Goldschmidt's publications in 1940, 1946, 1951, and 1955. The metaphors I discuss are: (1) the sentence metaphor, relating a chromosome to a sentence, and arguing for the significance of chromosomal *patterns* based on the significance of the *order* of the letters comprising a sentence; (2) the violin string metaphor, relating a chromosome to a vibrating violin string, emphasizing that localized effect does not imply localized independent units of action (thereby rejecting the inference from localized mutations to the existence of corpuscular genes); (3) the molecular analogy, relating the activity of a chromosome to that of a molecule, emphasizing that it is whole molecules that react, not their loci independently and, analogously, the chromosome genic action must be understood in a non-atomistic way; (4) the analogy between the genetic material and protein molecules specifically, emphasizing the significances of the order of sub-units; (5) the spectrum metaphor, relating the action of chromosomal sections to the actions of ranges of light waves on a organism in order to suggest how chromosomal segments can lead to a hierarchy of units of action; and (6) the mosaic block metaphor, relating chromosomal patterns to mosaic paintings, in order to emphasize the non-gradual effects of chromosomal pattern changes.

As this list shows, the metaphors, while related, emphasized subtly different things. I show how the different aspects work together in

² Clearly it was also related to a lot of previous work Goldschmidt has published on the nature of genes, and was a topic of fundamental significance to Goldschmidt's own professed field, genetics.

Goldschmidt's articulation of his conception of the gene, as well as unfolding their chronological development in his publications on the subject.

Metaphors of Genic Structure and Action

Goldschmidt presented his general argument about macro-evolution in 1933 in *Science* (Goldschmidt 1933). The term "hopeful monsters," which became synonymous with Goldschmidt's views, was introduced here. A much enlarged and more closely argued presentation of many of the same central ideas is contained in his 1940 book *The Material Basis of Evolution*, which was based on his Silliman Lectures delivered in 1939. The evolutionary argument, about the role of macro-mutations in speciation and the reality of incipient species, will not be discussed here. Rather Goldschmidt's genetic notions will be the focus.

In specific terms, the discussion is not about Goldschmidt's theories concerning how genes control development (i.e., physiological genetics), but rather how genes are embodied in the genetic material; that is, in the chromosomes. However, since the fundamental tenet of Goldschmidt's theory of the gene was the rejection of particulate genes by attributing genetic action to the serial pattern of the chromosome, both structure and activity are mingled in his discussion. To a large extent, Goldschmidt's metaphors are an answer to the quandary as to how organization of the genetic material can underlie what genes appear to do: how pattern determines activity. This, rather than the details of the genetic control of physiology, is what is at stake. For this reason, the same metaphors could be used in discussing both genic action and the nature of the genetic material (cf. Goldschmidt 1955, 481). A case in point is the use of metaphor in Goldschmidt's rejection of the argument for the existence of particulate genes based on mutational evidence (Goldschmidt 1946). To the question of what mutations tell about the nature of genes, Goldschmidt answered that they identify the effects of localized change, but do not establish the extent of the functioning gene. Since the question of how to interpret mutational evidence was asked by researchers working within the framework of the gene (see Carlson 1966, ch. 17), it is instructive to note that Goldschmidt's argument in 1946 regarding this question about genes, employs the same violin string metaphor that was used in Goldschmidt (1940) to explicate the idea that the genetic material is not composed of "theoretical" units or genes at all.³

As the title of Goldschmidt's 1940 book suggests, he considered his

³ In Goldschmidt (1937b) he makes it clear that in his opinion "gene mutations have as little existence as genes themselves."

views to be materialistic (the conclusions section of the book emphasizes this point as well) – in the sense of rejecting vitalism - while, at the same time, he rejected the notion of a corpuscular or atomistic gene. Goldschmidt's evolutionary ideas will not be discussed here at length but it should be mentioned that he saw his evolutionary argument as a separate line of argument leading to the same conclusion about the notion of genes as his arguments based on genetics. Both arguments will be presented here only in so far as they are needed to explain the context of Goldschmidt's metaphors.

After concluding that chromosomal pattern differences are distinguishing features of species (1940, 199) and arguing that empirical research suggests that the “intimate serial pattern of the chromosome is important for the action of the hereditary material” (1940, 201) Goldschmidt argues that the genetic effect does not depend in any way on “eventual” and “theoretical” units such as genes (1940, 202). The question to be addressed he argues is “how a change of the serial pattern within the chromosomes can be conceived as having evolutionary significance” (1940, 200). Focusing his attention on the notions of position effects and “gene neighborhoods,” he argues that pattern effects rather than being position effects of atomistic genes are independent effects of the whole chromosomes or of subsections of it (more on the distinction between these two cases below). To illustrate his conception of genetic effect of the pattern of the whole chromosome or sections of it, Goldschmidt then describes two “models” or “similes” (his terms).

A violin string as a whole may produce the tone A; if the string is stopped at a certain point, the tone becomes C. The constitution of the string has not been changed, but only its vibrating length; i.e., pattern. Or the letters e, o, r, s read “rose” in one order, and “sore” in another. (Goldschmidt 1940, 203)

And, with reference to (the non-gradual) affect on development:

Model: two different pictures produced with *the same set* of mosaic blocks, the new picture “emerging” only when all blocks are in their proper place. (Goldschmidt 1940, 203, my italics)

Goldschmidt was prepared for his view to be “misunderstood.” He explicitly states this in a footnote in which he mentions that he presented his ideas about macro-evolution being independent of gene mutations, indeed even of the concept of the gene, and being the result of chromosome patterns, but did not publish these notions before since he feared that his “position would be misunderstood if not properly documented” (Goldschmidt 1940, 205, fn. 1). A page later he claims

that his view is unavoidable but requires “a certain elasticity of mind” since the “fetters of the atomistic gene theory” need to be thrown off (p. 206).

Clearly, if one is afraid of being misunderstood and is aware of suggesting a radical break with mainstream thought, one would prefer to give a clear and convincing argument, and not an abstract and metaphoric model. Goldschmidt was, in addition, not only arguing against the mainstream of genetics but also against the Neo-Darwinian orthodoxy – all the more reason to be wary of being rejected. Two questions spring to mind. First, why provide the metaphors at all? These were not going to be sufficient to persuade hardened experimentalists (cf. Allen 1974); indeed, metaphors might weaken the argument by making it seem less rigorous. Why not let the accumulated evidence speak for itself? Second, what does the inclusion of the metaphors tell us about the target audience of Goldschmidt’s discussion?

The first question suggests that Goldschmidt employed the metaphors not solely for rhetorical purposes. Other than as a rhetorical device, two other reasons suggest themselves for introducing these metaphors. First, Goldschmidt might be grappling with making his notions of chromosomal patterns intelligible *to himself*. In such an endeavor there is a place for visualizations of various kinds, thought experiments etc. Second, aside from personal intelligibility, Goldschmidt may have felt that without *some* concrete model, the notion of the affect of a pattern might be considered incoherent (Goldschmidt remarks often that the idea is hard to understand for mainstream geneticists, who are used to the atomistic view of genes). Any model would thus serve to show *in principle*, the possibility of such a phenomenon. For this purpose any model, however metaphoric, is better than suggesting no model at all.

The second question raises more subtle interpretive concerns. *The Material Basis of Evolution* clearly revolves around evolutionary questions. As I mentioned earlier, the book is to a large extent an elaboration of Goldschmidt’s 1933 paper, which did not contain a discussion of the effect of chromosomal patterns at all.⁴ Had the metaphoric account of gene action been presented as an illustration of well understood processes, its use would have suggested that the target audience includes non-geneticists. But the metaphors are used to illustrate a speculative genetic idea and to show how it could be made sense of – the type of argument one would probably present to an audience of geneticists (and that we

⁴ Goldschmidt reports in his autobiography (Goldschmidt 1960, 322) that the earliest presentation of his non-corpuscular views was published in his book *Physiological Genetics* (1938b); a slightly earlier hint of this view was given by him in a lecture delivered in 1937 (Goldschmidt 1938a).

will soon see he indeed presented in genetics conferences). Supporting this conclusion (which I argued for based on the use of metaphor) is Goldschmidt's announcement at the beginning of the book that he is "attacking the problem [of evolution] as a geneticist." In the 1933 paper he describes geneticists – explicitly including himself – as not being able to keep the evolutionary aspects of genetics out of their heads, so that "from time to time [they] like to leave their bottles, breeding cages and seed pans and to review that advances of experimental work in regard to their bearings on problems of evolution." Goldschmidt's professional allegiances are clear.⁵

I suggest then that Goldschmidt's use of metaphors, specifically those intended to illustrate the possibility and intelligibility of a speculative scientific idea, provides an important clue as to the identity of the target audience as well as the professional self-identification of the scientists. Even in the midst of *The Material Basis of Evolution*, ostensibly a book about evolution, geneticists represent Goldschmidt's target audience. While there are other clues that can be used to verify this conclusion, including reference to specific research and citations of researchers, I turn now to the fundamental role that metaphors played to explicate the nature of the genetic material in Goldschmidt's central notion in *The Material Basis of Evolution*, represented here by the idea of "systemic mutations." Goldschmidt used the term to refer to chromosomal re-patterning. He observed that new species are usually chromosomally different from their parental species and suggested that evolution above the species level usually involves such re-patterning. Thus, this became the central mechanism of his conception of macro-evolution. Subsequently, the study of this mechanism, assuming Goldschmidt would be able to convince his readers that it exists, belongs to the field of genetics.

In order to elucidate the notion of systemic mutation Goldschmidt employs the metaphors he introduced earlier to account for genetic effect.

We may now use one of these models as a simile for the systemic pattern mutation. Let us compare the chromosome with its serial order to a long printed sentence made up of hundreds of letters of which only twenty-five different ones exist. In reading the sentence a misprint of one letter here and there will not change the sense of the sentence; even a misprint of a whole word (*rose* for *sore*) will hardly impress the reader. But the compositor might arrange the same set of type into a completely different sentence with a completely different meaning, and this in a great many different ways, depending upon the number of permutating letters and the complexity of the language (the latter acting as "selection"). (Goldschmidt 1940, 248)

⁵ It is worth mentioning that, in contrast, Goldschmidt's discussion of evolution is much less metaphorical, "hopeful monsters" notwithstanding.

While similar to the convention of representing the order of genes on chromosomes using strings of letters (e.g., Dobzhansky 1937), for Goldschmidt the letters do not represent particulate genes. A string of letters is an appealing way for representing a linear structure and reordering is easily modeled as permutating the string. The sentence metaphor builds on the strings of letters notation by adding function as well as structure to the model. A reordering of the letters within a sentence (structure) may lead to a change in meaning (function), though such a change, as Goldschmidt emphasizes, is not a necessary result of structural change.

In the lines following the sentence metaphor, as a “chemical model for visualizing” the re-patterning process but definitely not “as a hypothesis of chemical chromosomal structure,” Goldschmidt suggests:

Let us compare the chromosome to a very long chain molecule of a protein
As it is known each protein . . . is characterized by the length of the chain, the type of amino acid residues, and the specific order or pattern or rhythm of the repetition of these residues along the chain, innumerable types of protein may be obtained by permutation of these three variables, without any change within individual residues, the loci of the chain (Goldschmidt 1940, 248)

This description is reminiscent of Goldschmidt’s earlier theory of the gene, in which he argued that the different alleles represent different quantities of the gene and that this dosage effect controls the rate of reactions (Goldschmidt 1928). Developed in the context of the debate on the nature of position effects, Goldschmidt’s molecular metaphor quoted above is also suggestive of the side-chain theory of the structure of the gene (Thompson 1931), according to which the gene consists of a main particle to which varying numbers of one or more kinds of other particles are attached. Muller, in 1936, emphasized the distinction between a quantitative balance account of the “barred” eye phenotype and one based on position effect and, hence, chromosomal rearrangements, and argued for the latter (Carlson 1966, 115). Goldschmidt’s “chemical model” generalizes and abstracts these ideas in an attempt to explicate the notion of re-patterning.

The general structure of this strand of the argument is thus as follows: in order for Goldschmidt’s evolutionary account to be viable he had to provide a plausible genetic theory in which macro-mutations (which have big phenotypic effect and are responsible for reproductive isolation) are intelligible. His genetic theory, based on chromosomal patterns, fills this role. Macro-mutations, according to this theory, are *systemic mutations* or chromosomal repatterning events. Examples of chromosomal differences between species (i.e., evolutionary examples),

in turn, provide added support to the chromosomal pattern view of the gene. An alternative though complementary perspective on the relationship between the genetic and the evolutionary theories is that one reason to reject rearrangements as the sole source of mutations may be the appeal to the role of genes as units of evolution. This argument (attributed by Goldschmidt to Muller, see Muller *et al.* 1935) is mitigated if one provides an evolutionary account that is based on chromosomal repatterning (Goldschmidt 1946). While Goldschmidt explicitly argued that his account of macro-evolution does not *depend* on the notion of systemic mutations, only on the existence of single genetic changes which affect the entire reaction system of the organism simultaneously, he made it clear that in actual fact, according to his view, all of the genetic changes he discussed are systemic mutations (Goldschmidt 1940, 251-252). The discussion of macro-mutations in *The Material Basis of Evolution* is meant to show that saltatory change is within the developmental potentiality of organisms and accordingly the possibility of evolutionary saltations, and is not a tacit acceptance of ordinary gene mutations of macro-evolutionary effect (Goldschmidt 1955, 489). So while Goldschmidt did not argue that his account of macro-evolution depended on his theory of the gene, the two are subtly intertwined in his thinking and in the presentation of his ideas in *The Material Basis of Evolution*.

The appearance in 1941 of Beadle and Tatum's *Genetic Control of Biochemical Reactions in Neurospora* challenged Goldschmidt's account of genic action (i.e., reaction velocities, genic balance) and also provided renewed support to the notion of a corpuscular or atomic gene which Goldschmidt rejected. Goldschmidt expressed admiration for this work (Goldschmidt 1946, 252) but was not deterred, as can be deduced by his use of *the very same metaphor* from the 1940 book in a 1946 paper in which he argued that position effects are in fact the correct account of point-mutations, indeed for all genetic changes, and argued once more against the existence of "the corpuscular gene" (Goldschmidt 1946).

If I stop the A string of a violin about an inch from the base, the tone C is produced by the string. This does not mean that the string has a ^{+C} body at that point which, when stopped, becomes C. (Goldschmidt 1946, 252)

The 1946 paper provides a much more detailed argument connecting position effects and, hence, chromosomal patterns to the critique of the corpuscular gene than Goldschmidt provided in 1940. This makes it all the more remarkable that Goldschmidt (who, as the reader might have guessed, played the violin) felt the need to reuse this metaphor. The

context of use is subtly different, however. Whereas in 1940 Goldschmidt provides the metaphor to “illustrate [his] conception,” he uses it in 1946 to show why the argument from mutational side effects to the existence of definite genetic units (i.e. genes) is invalid. This is a much stronger use. Whereas the use of the violin example as an illustration of how genetic action is to be understood is very abstract and hence problematic, the use of this example in 1946 can be seen as not metaphoric at all but rather as a concrete counterexample to a specific line of argument.

Interestingly, while these metaphors suggest a holistic view of chromosomes and indeed Goldschmidt habitually talks about action of entire chromosomes,⁶ his view in fact provides room for sub-chromosomal action: “it is not a string of individual sections, genes, which individually produce the genic reactions, but that sections of any size, from the smallest size up to a whole chromosome, may be active units at one or another time (*hierarchy*)” [1946, 253, my italics; cf. the reference to subsections of chromosomes (Goldschmidt 1940)]. One might ask why the chromosome is the upper limit and not the whole genome, as a contemporary networks perspective might suggest. A specific argument is not given by Goldschmidt. Moreover, the discussion here is on Goldschmidt’s theory of the gene, not his account of the hereditary control of development (the “physiological theory of heredity”). As regards the latter Goldschmidt explicitly talks about a “network” of interaction (Goldschmidt 1955, 283, cf. Goldschmidt 1938). The upper limit of the unit of activity of the genic theory, in contrast, is chromosomal (for more details see Dietrich 2000b).

One has to wonder, however, if visualizing the chromosome as a vibrating string did not color Goldschmidt’s analysis, focusing it on the chromosome as unit and, concomitantly, deemphasizing the hierarchical conception of genic structure on which he elaborated (Goldschmidt 1946). Various commentators characterized Goldschmidt’s view as the chromosome-as-a-whole hypothesis neglecting his notion of a genetic hierarchy (Dietrich 2000b). Goldschmidt’s metaphors may have contributed to this especially since he reused metaphors invoked in *The Material Basis of Evolution* (1940) in his 1946 paper in which he elaborated on the notion of genetic hierarchy, as well as after that.

The hierarchical view of the chromosome is invoked by Goldschmidt to justify the notion of systemic mutations. While it is possible to argue

⁶ A clear example of this is the statement “The chromosome then is the unit, and a definite order within its texture is required for normal development” (Goldschmidt 1937a, 622-623). The same point is made in (Goldschmidt 1937b). Predicting the future of genetics, he wrote in 1940 that he was sure the model to come will be of “the chromosome and not the gene” (quoted in Carlson 1966, 126).

that the “chromosome as sentence” metaphor used in 1940 already implied a hierarchical understanding of the chromosome, by 1946 Goldschmidt explicitly connects the notion of hierarchical architecture of the chromosome to the very notion of systemic mutations

. . . the conception of the chromosome and its action as presented here permits purely architectural changes within a chromosome which change completely the action of the higher members of the hierarchy. At a certain level or threshold this might mean a profound change in chromosomal activity and therefore a profound change of the organism, if viable. *I have called this possibility a systemic mutation* (Goldschmidt 1941 [sic]). Goldschmidt 1946 my italics)

From a present-day perspective this description is highly suggestive (see Zuckerkandl and Cavalli 2007; reviewed in Grewal and Jia 2007). What is worth emphasizing, however, is that Goldschmidt is arguing for a hierarchical notion of genic action, an idea which is distinct from either a regulatory hierarchy (e.g., of particulate genes) or a hierarchy of developmental processes and phenotypic effects. While all three notions can coexist, they are not identical. Chromosomal rearrangements can lead to reproductive isolation and can have a large phenotypic effect, Goldschmidt argued in *The Material Basis of Evolution*. A holistic and non-corpuscular (but not necessarily hierarchical) theory of the genic action of chromosomes would have been enough for these claims and indeed even more mainstream genetics can incorporate these views (since the karyotype affects hybridization and isolation). Goldschmidt's claim here is stronger and connects the notion that genic action is inherently hierarchical to the very concept of systemic mutation.

Goldschmidt, in his attempts to relate genic action and position effects, suggests as a model a concrete hierarchy of chromosomal units (Goldschmidt 1946). At the lowest level the smallest visible segment is a single band in a salivary chromosome. A change in order of the constituents of such a segment (which become visible with treatment by urea) results, according to Goldschmidt in 1946, in what was then considered to be a point mutation. Next are larger segments, rearrangements which lead to typical position effects. The next level consists of alternating blocks of heterochromatin and euchromatin. The next level up, according to Goldschmidt, is the chromosome as a whole. Goldschmidt's discussion of this model hierarchy proceeds by assigning letters to represent the constituents of each level. The smallest segment that “must be a chain of different protein molecules arranged in a definite order” is represented as “ $\alpha, \beta, \gamma, \delta, \epsilon, \zeta$ ” and then summarized as “a”; the next level consists of “*a b c d e f*”; finally we have “*A -> heterochromatin -> B -> heterochromatin*” etc. with *A* composed of

“position effects sections” *a b c d* etc. (all quotations from Goldschmidt 1946) This description - intentionally extracted from the biological details Goldschmidt refers to in describing each level – emphasizes that the model here is closely related to the sentence metaphor (and to the phenomenon of rearrangement) and rather different from what one might have expected given the violin string metaphor, which as we saw earlier is used by Goldschmidt in this paper as a counterexample rather than a metaphor for genic action. It should be emphasized that none of the units just listed represents an individual gene, a notion Goldschmidt still rejected. It is position effects (i.e., patterns) that lead to genic action, not individuated genes.

In 1951, in an invited paper presented at the Cold Spring Harbor Symposium in a session dedicated to the “Theory of the Gene,” Goldschmidt once again uses a metaphor to *illustrate* (rather than prove) the notion of an overall action of chromosomal segments of different lengths.

We are now ready to take up the problem of how the chromosomal segments are integrated to higher units of action within the chromosome. . . . I realize how difficult the visualization of this and the following points is for the geneticist who is accustomed to think only in terms of genes. Let us try to make the underlying ideas clearer by the use of a simile, which like all such comparisons should not be worked to death but considered only as a help towards visualization. If we study the action of light waves on an organism we may find definite actions of ultraviolet light of one single wave length, which we compare to the action of a single genetic locus. We might then find actions which are essentially the same over a number of wave lengths, say within the ultraviolet. Other actions may be typical for the entire ultraviolet or other part of the spectrum and finally some light effects may be the same over whole sections, e.g. the yellow-green sections of the spectrum. In this simile, we compare the single wave length to the mutant locus, a few wave lengths to a section and the other groups to larger and larger sections of a chromosome. (Goldschmidt 1951, 6; the metaphor is repeated in Goldschmidt 1955, 181)

The effect of the light waves on an organism is thus compared to the *action* of chromosomal segments.

In this paper (Goldschmidt 1951) Goldschmidt uses the spectrum metaphor to illustrate his idea and also uses the violin string metaphor once again in the strong way he did in 1946 – that is, as a counter example to the inference from mutations to genes – as well as an analogy between the genic action of chromosomes and molecular reactions (he, again, calls these examples “similes”).

The first has only a vague resemblance to what it is supposed to clarify. If the A-string on a violin is stopped an inch from the end the tone C is produced. Something has been done to a locus in the string; it has been changed in regard to its function.

But nobody would conclude that there is a C-body at that point. A better simile can be derived by comparing the chromosome or its parts to a molecule. The molecule reacts in a definite way. If at one point of the molecule a different radical is substituted, say by methylation or amination, the resulting molecule may have completely different reactions. Can we conclude that the point in the molecule at which the substitution was made is in control of the standard reaction of the molecule? I should say that in either case, before and after substitution, the whole molecule reacts, not its loci. (Goldschmidt 1951, 7; the molecular metaphor is repeated in Goldschmidt 1955, 190)

Interestingly, Goldschmidt (1951) refers to Mather (1946; 1948) as someone espousing similar ideas, and says that the diagram in (Mather 1948) is “the same which I have frequently used to explain my views” (Goldschmidt 1951; see fig. 1.).

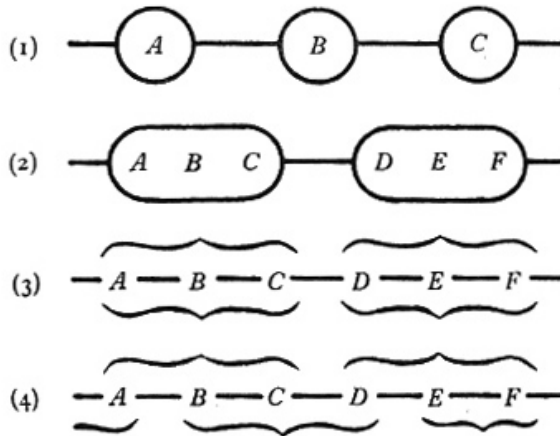


Fig. 1 - Figure 5 from (Mather 1948). The figure is also reproduced in (Goldschmidt 1955).

Mather, in contrast to Goldschmidt, did not feel the need to resort to elaborate metaphors, while Goldschmidt does not resort to similar diagrams in any of the papers and books discussed up to this point (the figure is, however, reproduced in Goldschmidt 1955). Ironically, Mather's somewhat metaphoric description of the chromosomal segments as “fields of cooperation” is objected to by Goldschmidt who approves of the notion of fields of action, but feels that the term “cooperation” suggests the existence of individuated subunits (Goldschmidt 1951; 1955).

It is appropriate to conclude this chronological presentation of Goldschmidt's metaphors of the genic action of chromosomal segments with his remarks about DNA in his 1955 book *Theoretical Genetics*.

According to [views about the composition of DNA], a mutation would mean a change in the relative number and order of purine and pyrimidine rings (but the difficulty is that the same type of process would have to account for mutation of the gene and for differences between different genes). (Goldschmidt 1955, 178)

Remarkably, Goldschmidt does not mention the similarity of this description to his sentence metaphor of chromosomal pattern nor to the protein analogy quoted above. This confirms Goldschmidt's commitment to the doubts he explicitly raises in this book about DNA being all there is to the genetic material. Considering how the notion of genetic sequence marginalized hierarchical perspectives on the genome, the decision not to relate the observation about nucleotide order to the sentential metaphor of chromosome pattern seems auspicious.

Discussion

I have shown the central metaphors Goldschmidt employed to elucidate his theory of the gene between 1940 and 1955. They are: (1) the sentence metaphor; (2) the violin string metaphor; (3) the molecular analogy; and, (4) the spectrum metaphor. In addition, Goldschmidt employed the mosaic block metaphor and the analogy between the genetic material and protein molecules.

Several aspects of Goldschmidt's views are represented in these metaphors. Some aspects are more pronounced in one metaphor than in others, while others are reflected in all or several of them. The significance of some aspects is clear from the explicit emphasis on them in specific metaphors, while the significance of others is revealed by the fact that they persist between several chronologically separate accounts. The seven main notions that can be identified are, first, the role of pattern and, more specifically, second, that of sequential patterns. Third, a hierarchical view of chromosomes, reflected in chromosome segments of increasing size is described. Fourth, the argument that specific effects of localized change do not imply existence of physical units of action at these locations and, five, that local effects do not imply that an active element (even if not an independent unit) is localized or local is also entertained. Sixth, the possibility of "emergent," non-gradual, and large scale changes in the developmental effects of genetic pattern changes is suggested. Perhaps more subtle is that all metaphors, with the exception of the detailed 1946 discussion of hierarchy, seem to suggest the seventh notion, a uniform account of all levels of chromosomal organization.

Goldschmidt was not alone in using metaphoric descriptions to

articulate the relations between genes and chromosomes. "Beads-on-a-string," the essence of the view Goldschmidt was arguing against, is itself a metaphoric description that was used at the time. Dobzhansky expressed this view with more rhetorical flourish when he described the chromosome as a "sausage stuffed with. . . genes" (Dobzhansky 1937, 115). The ideas of "gene neighborhoods" and "fields of cooperation," mentioned above, are also metaphoric in nature. I have attempted to show that Goldschmidt's metaphors were more than simply convenient summaries and served far more than rhetorical purposes.

Goldschmidt's repeated attempts to explain time and again, using different analogies, his discredited theory of genic action and indeed of the gene, reflects engagement, tenacity, and scientific optimism. They also reflect the fact that his central guiding idea regarding the notion of particulate genes did not change over the years discussed here, even if in other work done at the time he incorporated more mainstream ideas on the nature of genes (including homeotic mutations, see Dietrich 2000a).

I hope to have illustrated how following Goldschmidt's use of metaphors across several key texts illuminates his theoretical commitments (both changing and unchanging), his target audience, and sheds light on the points he feels more confident about and which points seem to him to require elucidation. The repeated use of the same metaphor, as well as the introduction of a new metaphor to make the same (or a very similar) point, are useful interpretive clues.

It is the nature of metaphors to emphasize some aspects of the phenomenon described at the expense of others. Two types of questions thus come to mind. First, which aspects of the problem of genetic action did Goldschmidt's metaphors emphasize and which aspects did they neglect? Second, which aspects of Goldschmidt's thought about genetic action did his metaphors emphasize and which aspects did they neglect? The metaphors clearly manage to emphasize two of Goldschmidt's main concerns: that mutational evidence does not imply the existence of corporeal genes and the notion of systemic mutation (chromosomal re-patterning). They do not address the question of how the holistic pattern or pattern of activity (i.e., the vibrating string), is transformed into or leads to genetic affects. They also de-emphasize Goldschmidt's hierarchical view of the chromosome, especially the violin string metaphor that can be misinterpreted as suggesting that the chromosome should be understood as a uniform string.

There is an interesting tension between two of Goldschmidt's central metaphors which points to a fundamental issue. Whereas the view of the chromosome as a long sentence made up of letters provides a good

alternative model to the notion of atomic genes, it is not in itself opposed to the idea of a passive container of genetic information, which determines activity but is itself passive. This type of mediated activity relation agrees with the one gene-one enzyme model, for example (and, indeed, the *Central Dogma*).⁷ It is worth emphasizing that the sentence metaphor, however suggestive from a modern perspective, is not used to illustrate that the chromosome contains *coded* information (recall the remarks about DNA quoted above). The coded message perspective raises its own individuating concerns, related but not identical to Goldschmidt's concerns.

Goldschmidt's second metaphor, of the vibrating violin string, is similar to the first in the rejection of atomic corpuscular genes but in contrast to it, suggests seeing the chromosome as actively taking part in the genic action or at least as being endowed with energy (this is also evoked by the molecule and spectrum metaphors). While Goldschmidt does not explicitly take up this issue, it can, perhaps, be seen as a step towards inquiring into the ontogenetic mutability of the genome, an idea that became associated with Barbara McClintock - whose work Goldschmidt praised (Goldschmidt 1950; 1951; Comfort 2001).

Perhaps one could be accused here of reading too much into Goldschmidt's metaphors. After all, Goldschmidt warned us that metaphors "should not be worked to death but considered only as a help towards visualization?" (Goldschmidt 1951). Nevertheless, there are several reasons why this will not do. As we saw, the metaphors are used for more than illustration purposes. They are a proof of possibility, are used as counterexamples to arguments made by others, and are a major thread running through Goldschmidt's thoughts over several significant years. More important, however, is that in the absence of definite biochemical account and with the experimental limits on studying minute re-patterning that existed at the time, Goldschmidt's metaphors are crucial for understanding the chromosomal gene theory he arrives at by equating all mutations with position effects (cf. Goldschmidt 1955, 162, 489). I think we are justified in using the model of genic action suggested by the metaphors to elucidate the consequences of Goldschmidt's perspective. Indeed, it is safe to assume that Goldschmidt did the same.⁸

⁷ Cf. Beadle & Tatum (1941) fn. 1.

⁸ In fairness it should be mentioned that Goldschmidt had a theory of genic action that may be considered to form this part of his more general theory of the gene, namely the notion of reaction velocities (rates) controlled by the typical quantity of the gene in different alleles (Goldschmidt 1928). It is beyond my scope here to consider whether this part of Goldschmidt's thought agrees with the chromosomal pattern view discussed in the current paper but, be that as it may, it suggests a highly restricted view of genes as patterns (i.e., one that is merely quantitative), which is surely not what

Allen (1974) mentions the influence of Alfred North Whitehead's anti-materialistic scientific philosophy with its emphasis on process and pattern, especially as espoused in his less technical writing and specifically his 1934 book *Nature and Life*.⁹ It is enlightening to see Whitehead's analysis of the introduction of the notion of pattern into science.

Apart from attention to this concept of pattern, our understanding of Nature is crude in the extreme. For example, given an aggregate of carbon atoms and oxygen atoms, and given that the number of oxygen atoms and the number of carbon atoms are known, the properties of the mixture are unknown until the question of pattern is settled . . . Thus, beyond all questions of quantity, there lie questions of pattern, which are essential for the understanding of Nature. Apart from a presupposed pattern, quantity determines nothing. Indeed, quantity itself is nothing other than the analogy of functions within analogous patterns. (Whitehead 1934, 17-18)

It is remarkable that Goldschmidt, whose theory of reaction velocities was quantitative in style, augmented it with a theory of chromosomal patterns. Goldschmidt was not the only biologist influenced by antimaterialistic scientific philosophy coming from the physical sciences, emphasizing the notions of waves and fields. Notably, Bateson, whose 1914 address Goldschmidt cited approvingly (Goldschmidt 1940), was influenced by similar ideas (Allen 1974; Darden 1977; Coleman 1970). Goldschmidt briefly discusses the connection between his hierarchical view of the chromosome, discussed here, and his contention that hierarchical order, resisting reductive explanations, is an essential property of living things in Goldschmidt (1954).

It is perhaps tempting to argue that Goldschmidt's use of metaphors reflects his tendency to argue by analogy (cf. Allen 1974). The specific examples discussed here, however, are clearly delineated as metaphoric in the texts they were taken from and were presented there as aids for understanding, not as conclusive arguments. The analogy between the *effect* on the organism of different wavelengths and chromosomal *activity* (referred to earlier as the spectrum metaphor) comes closest to being an argument by analogy, but the distinction underlying the analogy is arguably dissolved by Goldschmidt's physiological perspective. It should also be noted that Goldschmidt often presented several reasons or arguments in support of each of his conclusions. Even if the metaphorical language is to be considered as explanatory or even as an argument (since it

Goldschmidt tried to elucidate with his elaborate discussions of chromosomal patterns – epitomized by the metaphors I discuss here.

⁹ It should be stressed that antimaterialistic here does not reflect a vitalist tendency in Goldschmidt (which he explicitly rejects). "Anti-particleism" may be a better term for Goldschmidt's view.

purports to show that the type of organization Goldschmidt suggests is *prima facie* possible), clearly Goldschmidt did not present his metaphors as conclusive arguments.

Goldschmidt's "hopeful monster" metaphor remains his most well-known idea and continues to haunt his reputation. Historical justice demands that we not forget the other metaphors that he used.

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