Science in Context **19**(4), 443–474 (2006). Copyright © Cambridge University Press
doi:10.1017/S0269889706001037 Printed in the United Kingdom

The Verbal and the Visual in Science: A Heideggerian Perspective

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Argument

Heidegger's philosophy of science is notable for the prominence it gives to visuals and visualization. This is because for Heidegger, truth – including scientific truth – is the consequence of unconcealment, the lifting of a veil. But as scientific truth is a special kind, its visualization is also special: scientific truth reveals itself to us as, in Heidegger's words, "a calculable nexus of forces." This nexus unconceals itself largely by means of instrumentation: it is this process of revelation that turns objects into objects of science. Despite its focus on visualization, however, Heidegger's philosophy of science cannot be applied directly to scientific visuals. His categories are not designed with visual exegesis in mind. For that purpose, semiotics, the science of meaning as defined by Charles Peirce, is a necessary intermediary between the abstract and the concrete, a taxonomy of icon, index, and symbol that can be employed as a set of hermeneutic probes that permit the exploration of scientific visuals as embodiments and carriers of scientific meaning. But not their sole embodiments and carriers. In achieving scientific semiosis, the verbal and visual must combine their particular strengths. This is also in accord with a Heideggerian view: science moves methodically from the visual to the propositional, though it never leaves the visual behind.

In recent years, work on scientific visuals[1] on the part of historians, sociologists, and cognitive psychologists has proceeded at a pace so rapid that even the most cursory survey would require a lengthy review article. Work by historians begins with Martin Rudwick's seminal article, now three decades old. It is an isolated example ahead of its time. Brian Baigrie's 1996 collection, *Picturing Knowledge: Historical and Philosophical Problems Concerning the Use of Art in Science* marks a resurgence, the beginning of a new era of historical interest that now includes books by David Freedberg on the visuals produced for the Academy of the Lincei, Joseph Dumit on brain scans, and David Kaiser on Feynman diagrams. Sociologists have weighed in as well. In the wake of Michael Lynch's *Art and Artifact in Laboratory Science,* we have two comprehensive collections: in 1990 Michael Lynch and Steve Woolgar's *Representation in Scientific Practice* and in 2006

[1] Tables will not be dealt with; they are not scientific visuals; rather, they use the visual possibilities of the page in the interest of clarity, generally when masses of data must be presented. Like paragraphing and punctuation, they make the task of readers – in this case, readers of parallel sets of numbers – easier.

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Luc Pauwels' *Visual Cultures in Science.* Cognitive scientists have also contributed. They have been interested mainly in two topics: the heuristic value of visuals in the thought-processes of scientists and the cognitive processes involved in visual comprehension. On the first topic, we have the work of Herbert Simon and such collaborators as Jill Larkin, and on the second, that of Stephen Kossyln and Steven Pinker. Edward Tufte and William Cleveland may be counted in this group. Their interest is essentially ameliorative: it is to the improvement of graphics as carriers of information that they dedicate their work.

The purpose of this paper is not to extend this work; rather, it is to add to it an explanatory perspective, that of Heidegger's philosophy of science, a philosophy in which visuals and visualization play a central role. Despite its focus on visualization, however, Heidegger's philosophy of science cannot be applied directly to scientific visuals. His categories are not designed with visual exegesis in mind. For that purpose, semiotics, the science of meaning as defined by Charles Peirce, is a necessary intermediary between the abstract and the concrete, a taxonomy of icon, index, and symbol that can be employed as a set of hermeneutic probes that permit the exploration of scientific visuals as embodiments and carriers of scientific meaning.

In employing and extending the literature on the semiotics of scientific visuals – itself a robust field of investigation – there are, however, two dangers that must be avoided. The first is a reliance on models drawn from language, models that confuse language, ruled by a grammar that describes the internal and systematic relations between the parts of speech, with visuals, whose components have no such internal and systematic relationships. Gunther Kress and Theo van Leeuwen's otherwise very interesting work, for example, is undermined by their implicit reliance on M. A. K. Halliday's functional grammar. The second problem with the literature is the seeming reluctance to pursue a synoptic theory. Jacques Bertin and Françoise Bastide avoid general formulations. Bertin's semiotic work parallels in purpose the very differently oriented work of Tufte and Cleveland: it is theoretical only in the interest of amelioration. Bastide's sensitive analysis assumes but does not make explicit the semiotic theory of visuals driving her work.

Heidegger and Scientific Visualization[2]

There are two reasons why the philosophy of science of Martin Heidegger is a good choice when the object of study is scientific visuals. First, his is a philosophy centered on sight and insight. I do not mean that *Being and Time* and subsequent works are dominated by visual metaphors, although that is certainly the case; I mean rather that the significance of Heidegger's philosophy is inseparable from these metaphors. For

[2] My interpretation of Heidegger's philosophy of science and technology is informed by the sensitive commentaries of Glazebrook (2002) and Rojcewicz (2006).

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most philosophers, these, are, like Kant's dove, merely illustrative. Like the philosopher tempted by the snares of pure reason, Kant's dove "might imagine [wrongly] that its flight would be still easier in empty space" (Kant [1787] 1965, 47). For Heidegger, however, metaphor is a philosophical tool, a means of reaching beyond the conceptual prison of denotative language.

Meaning, for Heidegger, is conceived in terms of sight. Whatever is "ready-to-hand," that is, whatever is available for human use, becomes meaningful only by becoming visible as a thing of a particular kind:

> All preparing, putting to rights, repairing, improving, rounding-out, are accomplished in the following way: we take apart in its 'in-order-to' that which is circumspectively [*umsichtig*] ready-to-hand, and we concern ourselves with it in accordance with what becomes visible [*sichtig*] through this process. That which has been circumspectively [*umsichtig*] taken apart with regard to its 'in-order-to', and taken apart as such – that which is *explicitly* understood – has the structure of *something as something.* (Heidegger 1972, SZ 148-49; 1962a, BT189; emphasis his)

Truth is also a consequence of sight. We bring it to light: "If a *logos* as *apophansis* is to be true, its Being-true is *aletheuein* in the manner of *apophainesthai* – of taking entities out of their hiddenness and letting them be seen [*sehen lassen*] in their unhiddenness (their uncoveredness)" (ibid., SZ 219; BT 262). Since, for Heidegger, truth is unhiddenness [*Entdecktheit*], "to say that an assertion 'is true' signifies that it reveals the entity as it is in itself" [*in seiner Entdecktheit*].

There is a second reason for choosing Heidegger's philosophy for the investigation of scientific visuals: it does not privilege propositions. Instead, it regards science as an on-going activity whose existential encounters with the world are necessarily the primary focus of philosophical investigation. In *Being and Time,* Heidegger says that

> assertion is not the primary "locus" of truth. *On the contrary,* whether as a mode in which uncoveredness is appropriated or as a way of Being-in-the-world, assertion is grounded in Dasein's[3] uncovering [*im Entdecken*], or rather its *disclosedness.* The most primordial "truth" is the "locus" of assertion; it is the ontological condition for the possibility that assertions can either conceal or reveal the truth – can either be true or false. (Heidegger 1972, SZ 226; 1962a, BT 269; translation modified; emphasis his)

[3] In my opinion, Rojcewicz's explanation of *Dasein* cannot be bettered: "What is most decisive . . . in Heidegger's understanding of humans as *Dasein* is the precise meaning of the 'there.' The exact sense in which humans are called upon to be the place of a self-revelation of Being. This sense of 'there' (as also of *da* in German) is expressed very nearly in a colloquial use of the word in a context admittedly quite foreign to the present one. In the interpersonal domain, a parent may promise a child, or a lover a beloved, to 'be there' always for her or him. That is of course not a promise simply to remain at a certain place in space. Nor, at the other extreme, is it a claim of domination. Instead, it is a promise to be available in a supportive way; it is an offer of constant advocacy and nurture" (Rojcewicz 2006, 6).

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Not only are theoretical statements derivative, but interpretation exists, even in the absence of words: "Interpretation is carried out primordially not in a theoretical statement but in an action of circumspective concern [*umsichtig-besorgenden*] – laying aside an unsuitable tool, or exchanging it, 'without wasting words'. From the fact that words are absent, it may not be concluded that interpretation is absent" (ibid., SZ 218; BT 261; SZ 157; BT 200). Indeed, all communication, including scientific communication, is a communion simultaneously with others and with the objects of our concern: "when we are explicitly hearing the discourse of another, we proximately understand what is said, or – to put it more exactly – we are already with him, in advance, along side whatever it is the discourse is about" (ibid., SZ 164; BT 207; translation corrected).

In "The Era of the World Picture," Heidegger remarks that "the fundamental event of the modern age is the conquest of the world as picture (*als Bild*)" (Heidegger 1950, ZW 87; 1977a, EWP 134), a "structured image (*Gebilde*)" (ibid.). This "does not mean a picture of the world but the world *conceived and grasped* as a picture" (*als Bild begriffen*; ZW 82; EWP 129; emphasis added), one that permits us to see the world "its entirety . . . as a system" (ZW 82; EWP 129). What is the source of this view? The modern age. It and its key-stone, modern science, were inaugurated by two nearly coincident moments in the early seventeenth century, a philosophical moment, beginning with Descartes and culminating in Kant and its scientific counterpart beginning with Galileo and culminating with Newton. Heidegger explains this Cartesian-Galilean transformation in terms of his distinction between the "present-at-hand" (*vorhanden*), the system of concepts available to thought, and the "ready-to-hand" (*zuhanden*), whatever is available to human use. Science is what is "present-at-hand."

> Until Descartes every thing present-at-hand for itself was a "subject" but now the "I" becomes the special subject, that with regard to which all the remaining things first determine themselves as such. Because – mathematically – they first receive their thingness only through the founding relation to the highest principle and its "subject" (I), they are essentially such as stand as something else in relation to the "subject," which lie over against it as *objectum*. The things themselves become "objects." (Heidegger 1962, FD 57; WT 105)

For Heidegger, this paradoxical guarantee of objectivity by means of subjectivity defines modern science, which "is supposed to be based on experience. Instead, it has such a law [as Newton's first law of motion, which posits not real but unrealizable conditions] at its apex. This law speaks of a thing that does not exist. It demands a fundamental representation of things which contradict the ordinary" (ibid., FD 69; WT 89).

But the philosophical heirs of Descartes inherited a central puzzle: the link between mind and the world lacked a satisfactory explanation. For Heidegger, therefore, the philosophical moment of modern science culminates, not with Descartes, but with

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Kant. According to Kant, since neither pure reason nor its purely empirical counterpart can account for our knowledge of the everyday world or its derivative, the world as understood by science, we must have within us a set of categories and intuitions that permit us to see the world as extended in space and time and causally determined, that is, "mathematical" in the broad sense:

> the mathematical is that "about" things we really already know. Therefore we do not first get it out of things, but, in a certain way, we bring it already with us. From this we can now understand why, for instance, number is something mathematical. We see three chairs and say that there are three. What "three" is three chairs do not tell us, nor three apples, three cats nor any three things. Moreover, we can count three things only if we already know "three." In this grasping the number three as such, we only expressly recognize something which, in some way, we already have. This recognition is genuine learning. (Ibid., FD 57; WT 74)

Genuine knowledge, then, is a consequence of our interaction between the world and our inherent categories of understanding and our intuitions of space and time. This is the synthetic a priori, the source of what is scientific about our scientific knowledge:

> the mathematical, in the sense of what is movable in space, belongs first of all to the definition of the thingness of the thing. If the possibility of the thing is to be metaphysically grasped (*begriffen*), there is need for such principles in which this mathematical character of the natural body is grounded. For this reason, one group of the principles of pure understanding is called "the mathematical principles." This designation does not mean that the principles themselves are mathematical in the strict sense, but that they concern the mathematical character of natural bodies, the metaphysical principles that lay the ground of that character. (Ibid., FD 148-49; WT 190-91; translation modified)

In this broad sense, the intellectual movement from Galen to Vesalius is mathematical; in this sense also, a diagram by Darwin and a line graph by Hubble are equally mathematical.

The visualization of the world as an object guaranteed by the Cartesian subject and open to mathematics and measurement is also at the center of modern science: "that the world becomes picture is one and the same event with the event of man's becoming *subiectum* in the midst of that which is" (Heidegger 1950, ZW 85; EWP 132). It is a picture whose frame differs from the ordinary in that it *determines* the meaning of the picture it contains. It is the En-framing (*Ge-stell*) of everyday experience that creates a rigorously articulated system of efficient causes and effects arrayed in space and time:

> Modern science's way of representing pursues and entraps nature as a calculable nexus of forces [*als einem berechtenbaren Kräftezusammenhang*]. Modern physics is not experimental physics because it applies apparatus to the questioning of nature. Rather the reverse is true. Because physics, indeed already pure theory, sets nature up to exhibit itself [*darzustellen*]

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> as a coherence of forces calculable in advance, it therefore orders its experiments precisely for the purpose of asking whether and how nature reports itself when set up in this way. (Heidegger 1954a, FT 29; 1977b, QT 21; translation modified)

In this connection, Heidegger quotes Werner Heisenberg: "The representing belonging to modern physics is also bent on 'being able to write one single fundamental equation from which the properties of all elementary particles, and therewith the behavior of all matter whatever, follow'" (Heidegger 1954b, WB 61; 1977c, SR 172).

This En-framing creates, not only modern science, but also modern technology, intellectual Siamese twins, science seeing the world as object present-at-hand, technology seeing it as ready-to-hand, as a standing-reserve, open to human use (*Bestand*). Heidegger argues that modern science and technology represent a particular attitude toward Being, one of exploitation. This general claim is not my concern; I am concerned only with the extent to which modern technology creates the instrumentation on which the experimentation and observation of modern science rests. For Heidegger: "modern physics, as experimental, is dependent on technical apparatus and upon progress in the building of apparatus" (Heidegger 1954a, FT 22; 1977b, QT 14). Observation in modern science is itself a technology, given Heidegger's definition of science as a "theory of the real": "*theôrein, horaô,* means: to look at something attentively, to look it over, to view it closely. Thus it follows that *theôrein* is *thean horan,* to look attentively on the outward appearance wherein what presences becomes visible and through such sight – seeing – to linger with it" (Heidegger 1954b, WB 52; 1977c, SR 163). Scientific instruments also include the human eye and, by analogy, the other four senses.

On occasion, En-framing leads to formulations allegedly incapable of being visualized, a frame apparently without a picture, as in quantum mechanics:

> If modern physics must resign itself ever increasingly to the fact that its realm of representation remains inscrutable and incapable of being visualized, this resignation is not dictated by any committee of researchers. It is challenged forth by the rule of En-framing, which demands that nature be orderable as standing-reserve [*Bestand*]. Hence, physics, in all its retreating from the representation turned only towards objects that has alone been standard until recently, will never be able to renounce this one thing: that nature reports itself in some way or other that is identifiable through calculation and that it remains orderable as a system of information. (Heidegger 1954a, FT 30; 1977b, QT 23)

In modern physics, it would seem "causality is shrinking into a reporting – a reporting challenged forth – of standing-reserves that must be guaranteed either simultaneously or in sequence. To this shrinking would correspond the process of growing resignation that Heisenberg's lecture [on the philosophical consequences of his indeterminacy principle] depicts in so impressive a manner" (Heidegger 1954a, FT 30–31; 1977b, QT 23). Yet, "even where, as in modern physics, theory – for

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essential reasons – necessarily becomes the opposite of direct viewing, its aim is to make atoms exhibit themselves for sensory perception, even if this self-exhibiting of elementary particles happens only very indirectly and in a way that technically involves a multiplicity of intermediaries (Compare the Wilson cloud chamber, the Geiger counter, the free balloon flights to confirm and identify mesons)" (Heidegger 1954b, WB 62; 1977c, SR 173). Despite this limitation, quantum physics is a consequence of the same En-framing as classical physics: "classical physics maintains that nature may be unequivocally and completely calculated in advance, whereas atomic physics admits only of the guaranteeing of an objective coherence that has a statistical character" (Heidegger 1954b, WB 61; 1977c, SR 172).[4] Despite this, as we shall see, the invisible world of quantum mechanics can be rendered visible without recourse to intermediaries: Heidegger was not aware of Feynman diagrams.

Heidegger and Semiosis

Scientific visuals form systems of signs; these require semiotic analysis if we are to understand just how they create and communicate the meaning Heidegger reveals. Peirce is my choice among semioticians as a thinker whose concepts are most compatible with Heideggger's metaphysics. His taxonomy is three-fold: icon, index, symbol. An icon is a sign that depicts; a photograph or a drawing of a microbe is an icon. An index is a sign whose relation to its object is causal or indicative. Geiger counter readings are causally linked to the external world; in a photograph an arrow pointing to a cell nucleus is merely indicative. A symbol is a sign whose relation to its object may be, but need not be arbitrary: the equal sign and He for helium are symbols; the first is wholly arbitrary, the second, a motivated sign, abbreviating a wholly arbitrary one.

It is important not to be dogmatic about these category assignments. As Gérard Deladalle points out: "we must insist... on the functional character of these distinctions: what is an index in one semiosis may be a symbol in another. Take, for instance, the symptom of an illness.... If this symptom is referred to in a lecture

[4] After the first part of *Being and Time,* we have from Heidegger not the second part, but only lecture series and occasional essays. In two lecture series – *The Phenomenological Interpretation of Kant's* Critique of Pure Reason (1927/28), and *What Is a Thing?* (1935/36) – he reflects on science; he also reflects on science in the following essays: "The Era [usually translated as "Age"] of the World Picture" (1938), "What Is Technology?" [usually translated as "The Question Concerning Technology"] (1953), and "Science and Reflection" (1953). I interpret these intellectual excursions as developments and elaborations of the intellectual content of *Being and Time* and therefore as consistent with *Being and Time* and each other. This involves, for example, assuming an equivalence between the *Entdeckung* of *Being and Time* and the *Entbergen* of "What Is Technology?" This equivalence is supported by an equivalence between "Entdeckheit" and "Unverborgenheit" in *Being and Time* (1962, 219). It also involves assuming a rough equivalence between what is *zuhanden* and *Bestand*. While these seem reasonable hermeneutic assumptions, it is only fair to say that that is all they are – assumptions. Heidegger gives us no help in this regard.

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on medicine as always characterizing a certain illness, the symptom is a symbol. If the doctor encounters it while he is examining a patient, the symptom is an index of an illness" (Deladalle 2000, 19–20). Context is central to semiotic interpretation. But, even without a change in context, variability of meaning is possible: the same indexical arrow is iconic in the sense that it reproduces recognizable features of an actual arrow; it is symbolic in that it represents deixsis. Sebeok makes the essential point:

> In general, it is . . . inane to ask whether any given subject "is," or is represented by, an icon, an index, or a symbol, for all signs are situated in a complex network of syntagmatic and paradigmatic contrasts and oppositions, i.e., simultaneously participate in a text as well as a system; it is their position at a particular moment that will determine the predominance of the aspect in focus. (Sebeok 1976, 1433n)

This understanding of Peirce's taxonomy is consonant with the views of Nelson Goodman, a position worth quoting at length:

> Comparative judgments of similarity often require not merely selection of relevant properties but a weighing of their relative importance, and variation in both relevance and importance can be rapid and enormous. Consider the baggage at an airport check-in station. The spectator may notice shape, size, color, material, and even make of luggage; the pilot is more concerned with weight, and the passenger with destination and ownership. Which pieces of luggage are more alike than others depends not only upon what properties they share, but upon who makes the comparison, and when. Or suppose we have three glasses, the first two filled with colorless liquid, the third with a bright red liquid. I might be likely to say the first two are more like each other than either is like the third. But it happens that the first glass is filled with water and the third with water colored by a drop of vegetable dye, while the second is filled with hydrochloric acid – and I am thirsty. Circumstances alter similarities. (Goodman 1972, 445)

To Peirce's semiotic triad, Ferdinand de Saussure adds an important element. For Sausssure, signs are meaningful only in so far as they participate in a system of value-laden differences:

> In all these cases what we find, instead of *ideas* given in advance, are *values* emanating from a linguistic system. If we say that these values correspond to certain concepts, it must be understood that the concepts in question are purely differential. That is to say they are concepts defined not positively, in terms of their content, but negatively by contrast with other items in the same system. What characterizes each most exactly is being whatever the others are not. (Saussure [1916] 1986, 115; emphasis his)

Saussure's principle is generalizable; it teaches us to concern ourselves, not only with relationships between visuals and the external world, but also with the internal relationships among the constituents of visuals, a concern absent in Peirce. It teaches us that a set of visual constituents, characterized solely by their difference from each

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other, can form a code. Alphabets are examples of such codes. Unlike the grammars of natural languages, alphabets form sets that lack any internal and systematic connections among their components. Of course, alphabets exist just to inscribe words and words exist just to form sentences that do exhibit internal and systematic connections among their constituents. In so doing, however, alphabets subserve grammars. The visual is a componential semiotics that must make do with sheer contiguity.

In the analysis of scientific visuals, it is important to strike a proper balance among the three dimensions of the Peircian triad: the iconic, the indexical, and the symbolic; especially, it is important to give particular weight to the indexical as against the iconic and symbolic. This is because the central task of science is the discovery of the causal structure of the world. In science, its underlying causal structure *accounts for* the phenomenal world; in turn, the phenomenal world *points to* its causal structure. Scientific visuals are iconic or symbolic only in the interest of indexicality, of revealing causation, characterized by Heidegger as "a calculable nexus of forces." It is this nexus that scientific visuals depict: those that are apparently iconic are actually indexical, pointing to a cause. It is the equation of indexicality and causation that forms the intellectual bridge between Heidegger and Peirce's triad. In the remainder of this paper, this claim will be supported by reference to the role of instrumentation in this process and to visuals that, despite important differences, share this common purpose. In addition, it will be shown that this claim about scientific visuals is general; it even applies – perhaps counter-intuitively – to the life sciences. Finally, it will be shown that there is in science a cycle of interpretation that, though it begins with the visual, ends in the propositional. This is not to say that the visual is marginalized; it is rather to say that, in the end, the visual is infused with the propositional or, to change the metaphor, but to maintain the Latin root, the visual and the propositional are fused.

Instruments "enframe" the world as a calculable nexus of forces

All of the visuals in Lavoisier's *Elements of Chemistry* are illustrations of instrumentation. This is no accident: all the effects Lavoisier writes about in a book that turns chemistry into a modern science are those of the instruments he uses. The general absence of illustrations of instruments in contemporary science is due not to their diminished importance, but to their standardization:

> The rapid movement of research equipment from one modification to the next is key to the mode of rapid discovery in which scientists take so much confidence; they feel that discoveries are there to be made along a certain angle of research because the previous generation of equipment has turned up phenomena which are suitable for the intellectual life of the human network. . . . The genealogy of equipment is carried along by a network of scientific intellectuals, who cultivate and cross-breed their technological crops in order to produce empirical results that can be grafted onto an ongoing lineage of intellectual arguments. (Collins 1998, 870–71)

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Scientific visualization is intrinsically technological, that is, scientific visuals are created, most often with the aid of instrumentation, but always under the dominance of a technological attitude that applies even to observations made without the benefit of instruments. In this process, visuals are stripped of their everyday significance – all connection with the world we ordinarily experience is severed. As a consequence, they must be re-contextualized in a new world, one in which the calculable nexus of forces is the overriding concern.

Instrumentation, then, is not epistemically innocent; in Heideggerian terms, it enframes. My examples illustrate three instances of such instrumental enframing, moving from what is visible to the unenhanced eye, to what is visible to its enhanced counterpart, to what is in principle not visible at all: the telescopic, the microscopic, and the sub-microscopic. My first illustration is from Galileo's *Sidereus Nuncius.* In this case, the telescope has brought a visible far-away object close enough for us to see its irregular features, those that the engraving emphasizes by its manipulation of light and shade. The pervasiveness of these irregular features leads Galileo to the following conclusion: "By oft-repeated observations of [these spots] we have been led to the conclusion that we certainly see the surface of the Moon to be not smooth, even, and perfectly spherical, as the great crowd of philosophers have believed about this and other heavenly bodies, but, on the contrary, to be uneven, rough, and crowded with depressions and bulges. And it is like the face of the Earth itself, which is marked here and there with chains of mountains and depths of valleys" (Galileo [1610] 1989, 16).

In its new, scientific context, this illustration is no mere illustration. It is rather a challenge to existing theory, inviting the reader to compare the earth and the moon and to draw an inference from the comparison: if the earth and the moon are similar in these ways, as the telescope reveals, the same physics may apply to both, a conclusion bound to upset astronomers and theologians equally. An iconicity that only the telescope has revealed has been transformed into an index of a uniform physics not limited to the sublunar (fig. 1).

Next is Leeuwenhoek's illustration of a male flea's reproductive organ, derived from microscopic observation (fig. 2). Bringing the flea so uncomfortably close that it reveals detail otherwise invisible allows Leeuwenhoek to go beyond mere description, however accurate. He is interested not only in the configuration of the flea's reproductive organ that the microscope reveals, but in an inference from this configuration:

> This Flea also brought a short portion of its Male Organ several times out of and into its Body, and this Organ, in coming out, passed through or between the two parts which are indicated in [the figure] by P and Q .... And during this passage the knotty part alters its form, for I then saw in two different places, on the underside of the knotty part of the Male Organ, two small long parts shooting out, which were about four times as long as they were thick and whose length was about the same as the thickness of the Male Organ below the knot. And when the Flea began to draw the Male Organ back again into the Body, the said Parts, which had been thrust out obliquely downwards, were drawn in

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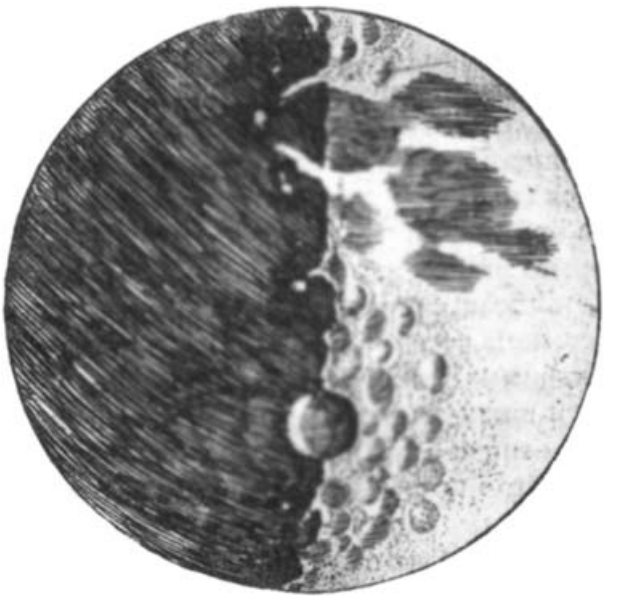


Fig. 1. Galileo's Moon. In *Sidereus Nuncius*, or, *The Sidereal Messenger*, 1610.



Fig. 2. Leeuwenhoek's Flea. In *The Collected Letters of Antoni van Leeuwenhoek*, 1693.

> again, while in addition and at the same time another third small part or Member was thrust out of the Male Organ as it was carried through the said parts. This thrust-out Member corresponded very closely in length and thickness to the aforesaid Parts, and this latter Member was thrust out very nearly straight upwards, and was also brought inwards again as the Male Organ was drawn in. *On seeing this, I wondered whether the Male seed might not be conveyed through this latter thrust-out member* (Leeuwenhoek [1693] 1976, 247; emphasis added).

More than physiological curiosity motivated Leeuwenhoek's observations of the flea. He was interested in a larger question, the doctrine of spontaneous generation,

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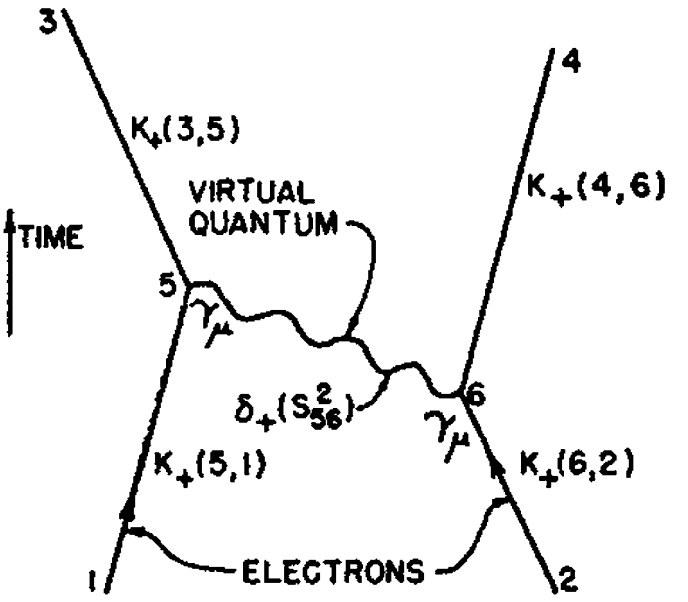


Fig. 3. Feymann Diagram. In "Space-time Approach to Quantum Electrodynamics." *Physical Review*, 1949.

the widely held belief that lower forms of life could be generated from inanimate materials, such as animal feces. If fleas had reproductive equipment analogous to that of human beings, was it not obvious that the origin of fleas was not inanimate matter, but other fleas? Leeuwenhoek's is, simultaneously, a depiction of a flea's sexual organ, its functioning, and a presentation of evidence against spontaneous generation. While the organ's depiction is iconic, its real function is indexical; the organ *points to* its functioning. At the same time, its functioning is itself indexical; it *points to* a causal theory – generation through reproduction.

My last illustration in this section is of a physical process apparently not visualizable because in principle beyond the reach of instrumentation. Despite Heidegger's pessimism, however, in quantum physics even the unvisualizable can be visualized. To explain this new physics, Richard Feynman devised a new kind of visual, the eponymous Feynman diagram, a visual inferred from a theory that must conform to instrumental readings. The diagram shows the billiard-ball-like paths of two interacting electrons in space and time (fig. 3).

To understand this depiction of the subatomic world, the diagram must be read from bottom to top. The straight lines with arrows represent the paths of electrons, the gammas (γ), along with their mus (μ), their four possible polarizations or orientations. These K_+'s are not the paths exactly, since the square of these "amplitudes" is not the event, but only its probability. In Feynman's words: "It is not of interest to be able to

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say how the situation would look at each instant of time during a collision and how it progresses from instant to instant. Such ideas are only useful for events taking a long time and for which we can readily obtain information during the intervening period. For collisions it is much easier to treat the process as a whole" (Feynman 1949, 771).

In its apparent determinacy, this visualization may seem at odds with Heisenberg's indeterminacy principle. But it is not. While the photographs taken in Wilson's cloud chamber actually depict the visual traces of the subatomic world, Feynman diagrams do not: nothing in that world necessarily corresponds to the paths in the diagram: the paths correspond only to probabilities. This representation conforms perfectly to a Heideggerian view of science; it "enframes" the world as a "calculable nexus of forces," but a nexus that can now be explained only in terms of probability.

A calculable nexus of forces: a variety of realizations of the same phenomenon

The calculable nexus of forces that scientific visuals represent is realized in a variety of ways, photographs, diagrams, graphs, line graphs, each with its own particular strengths in creating and conveying indexical meaning. Photographs are a regular means by which scientists represent the world and by so doing create and communicate meaning. Wilhelm Röntgen's X-ray photographs are an example (figs. 4 and 5). What is being depicted? That depends on who is doing the looking. While these images reproduce the skeletal structure of the human hand, clearly their most salient feature, this result was in itself of no interest to the physicists who found the photographs arresting; to them, the hand was merely a representative instance of the existence and the power of these newly discovered rays: the second photograph was to be preferred because it gave us a more convincing demonstration of this power. Physicians shared this preference for the second X-ray. But for a different reason; for them the photographs were emblematic of the ability of the rays clearly to represent medically salient aspects of the interior of individual living beings, an exposure useful for diagnostic purposes. In both cases, the X-ray is indexical, evidence for a causal claim: the means of seeing through flesh in the case of physicists, the means by which an otherwise invisible physical feature is revealed in the case of physicians. This evidential value resides in the fact that, along with their radioactivity-generated siblings, autoradiographs, X-rays, in revealing the interiors of bodies, simultaneously reveal themselves as a form of light that reveals the interior of bodies. No verbal description, no diagram could accomplish this task and serve this evidentiary purpose. For this reason, when Röntgen sent his paper recording his discovery of X-rays to Lord Kelvin – a paper, oddly, entirely devoid of photographs – he was careful to include such X-rays in the envelope (Mould 1993, 7–8).[5]

[5] In recent years, this evidential value has been somewhat compromised by the extensive use of Photoshop(c) to alter the originals: "In 1989–90, only 2.5 per cent of allegations examined by the US Office of Research

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—Picture of a hand which Röntgen sent to the Vienna physicist, F. Exner. The original plate is in the Deutsche Museum, in Munich, and according to a note by Röntgen, was made on December 22, 1895.

Fig. 4. Roentgen's First Hand. In Richard F. Mould, *A Century of X-Rays and Radioactivity in Medicine, With an Emphasis on Photographic Records of the Early Years*, 1993.

Photographs are not the only visuals scientists employ. Diagrams are also an important vehicle in the creation of scientific meaning. An example is Ole Roemer's seventeenth-century diagram of Jupiter's moon, Io, viewed from various positions on earth's orbit around the sun. Roemer imagines the astronomical system he depicts as a

Integrity, which monitors misconduct in biomedical research, involved contested scientific images. By 2001, this figure had jumped to nearly 26 per cent" (Peterson, 2005, 952). But the matter is by no means clear-cut, since some enhancements, such as false color in astronomy, actually add to evidential value. False color alters iconicity in the interest of altering indexicality; it represents features "true" color would hide or obscure.

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The picture of the hand of the anatomist, von Kölliker, made on the occasion of Röntgen's lecture before the Würzburg Physical-Medical Society, on January 23, 1896.

Fig. 5. Roentgen's Second Hand. In Richard F. Mould, *A Century of X-Rays and Radioactivity in Medicine, With an Emphasis on Photographic Records of the Early Years*, 1993.

gigantic celestial clock (fig. 6). Two of the positions of Io's orbit – the clock's "hands" – are represented at the top of the diagram by the indexical letters D and C, symbols separated by a series of vertical lines that show when Io is hidden behind the planet. The earth's orbit is the lower circle; the diagonals are symbolic representations of lines of sight between us and Io.

If we tell time by Io, Roemer discovers, we find that our clock is not accurate; as the earth moves away from Jupiter, we lose time; as it moves toward Jupiter, we gain time back. In Roemer's words: "In the nearly forty-two and a half hours that the moon takes for each of its revolutions, the distance between the earth and Jupiter, as the earth travels in its orbit, changes at least 210 earth diameters. Because of this, it follows that if, for the value of each earth diameter, a second is needed, light will take three and one half minutes to traverse each of the intervals *GF,* and *KL,* a period that will create a difference of seven minutes between the two revolutions of Io, the one observed in *FG,* the other in *KL,* although no difference at all may be perceived at each individual sighting" (Roemer 1676, 234–35). It is Roemer's conclusion that this variation could not occur if the speed of light were infinite.

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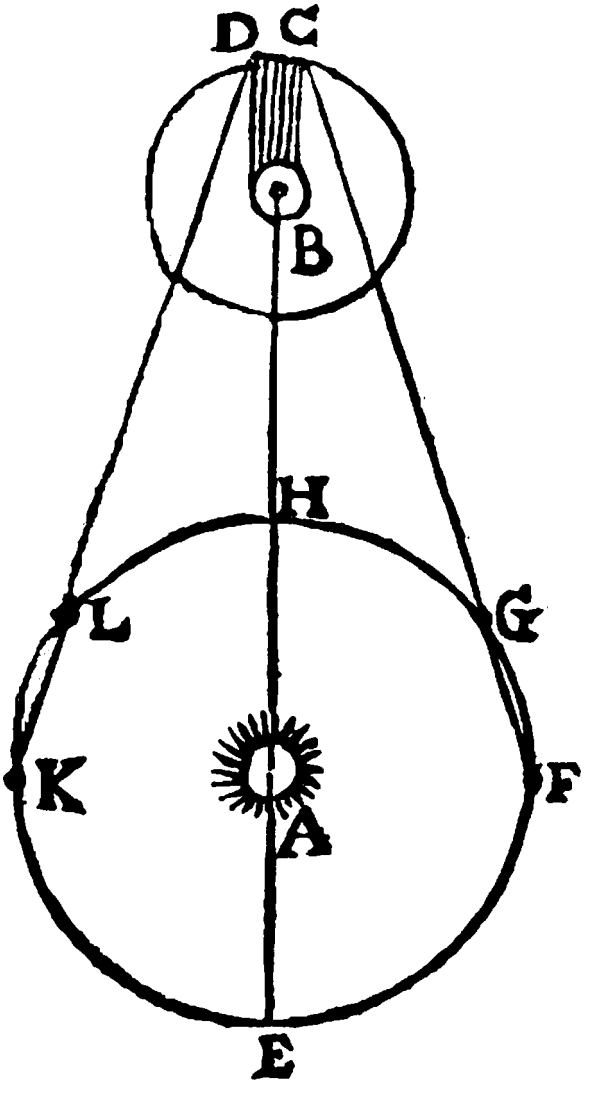


Fig. 6. Roemer's Clock. In "Demonstration touchant de le Mouvement de la lumière." *Journal de Sçavans*, 1696.

Plainly, the diagram's purpose is not to depict the relative positions of Io and earth; there would be no need to represent a fact so obvious to astronomers of the time. In addition, Roemer makes no attempt to represent with accuracy planetary and lunar orbits or the sizes of the astronomical objects; these are also irrelevant to his purpose. Instead, his diagram depicts his proof that the velocity of light is finite. It is iconic of this proof, an icon in the interest of indexicality: the diagram points to the causal

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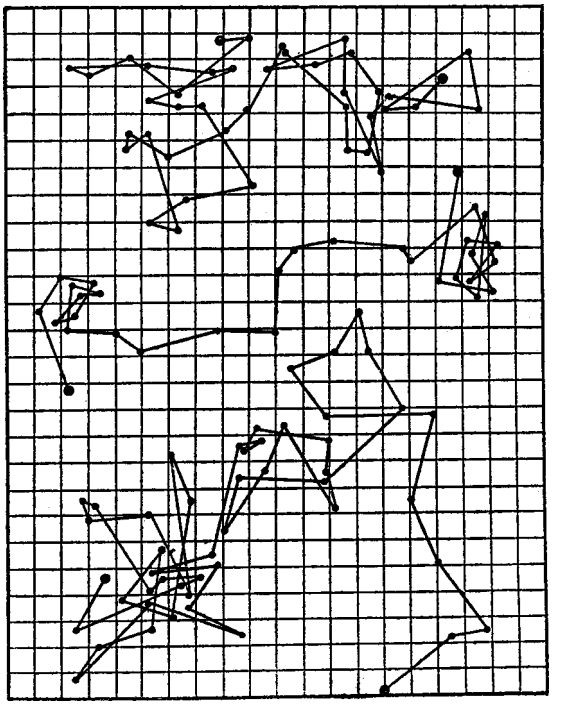


Fig. 7. Perrin's Graph. In "Mouvement brownien et réalité moléculaire." *Annales de Chimie et de Physique*, 1909.

structure on which the proof rests. This proof requires, and the diagram enables, not only *seeing*, but also *seeing through* celestial appearances so as to capture only those causal characteristics that count as premises relevant to the proof. No photograph can accomplish this purpose.

Graphs, another routine form of scientific visualization, are represented here by two very different types, Perrin's record of Brownian motion and Hubble's representation of the relation between the distance and velocity among extra-galactic nebulae. Perrin records Brownian motion, the apparently random and perpetual motion of very small bodies suspended in a liquid, caused by analogous movements at the molecular level. Or so Einstein had conjectured. Perrin's long paper was designed to confirm this conjecture (fig. 7).[6]

[6] It might be thought that theoretical papers such as Einstein's first four on Brownian motion, which do not contain visuals, are an important class of exceptions to any rule that visuals are central to science. But any line drawn between Einstein's paper and Perrin's is entirely artificial: every theoretical paper anticipates experimental or observational validation.

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Concerning this jagged graph line, each segment of which represents a thirty-second interval, Perrin argues as follows:

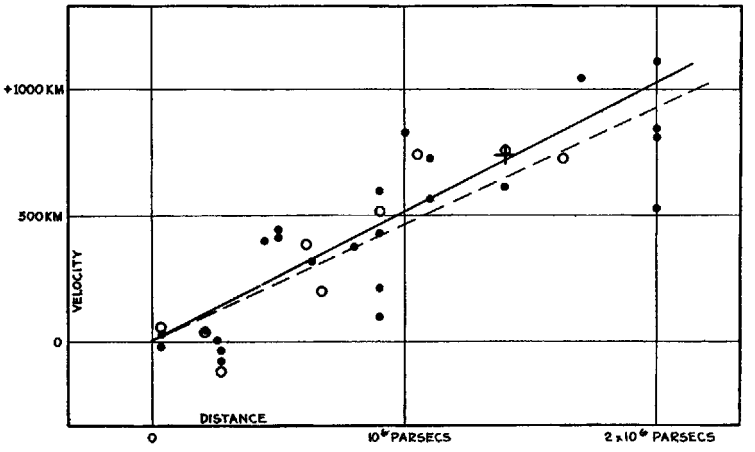
> One of these drawings shows [nearly 50] consecutive positions of the same granule. These positions give only a very feeble idea of the prodigiously complex character of the real trajectory. If the positions were indicated from second to second, each of these rectilinear segments would be replaced by a polygonal contour of 30 sides, relatively as complicated as the drawing here reproduced, an effect that would keep repeating itself as we plotted shorter and shorter periods of time. From such examples, one realizes how near the mathematicians are to the truth when, through logical instinct, they refuse to admit as experimental evidence for the continuity of matter the geometric truth that, for each point on a curve, there exists a tangent. (Perrin 1910, 63–64)

What does Perrin mean by this last statement? He means that mathematics is not physics. At its limit, a polygon of infinite sides becomes a circle, that is, in mathematics, at the limit, the discontinuous becomes continuous. But it does not follow that the constitution of matter is such that the discontinuous will become continuous; it does not follow that, if you map molecular collisions at smaller and smaller intervals, points of collision will disappear and a smooth curve will supervene. In effect, Perrin's is one in a series of possible graphs, each of which would map smaller and smaller intervals, approaching but never reaching continuity.

Perrin's graph resembles a map. It transcribes in two-dimensional space the three-dimensional events that constitute his evidence for the molecular origin of Brownian motion. While his graph is iconic, its evidential value, like that of photographs or autoradiographs, stems from its indexicality, the causal connection we infer between the phenomenon in question – molecular agitations – and the paths we actually see. The analogy is with Röntgen's X-ray; from the point of view of science, it is nature that moves the recording needle and creates the graph. In the Perrin's case, however, it is not the object that is salient, but the pattern over time.

The relationship between the phenomenal world and its representation is more complex in Edward Hubble's line graph (fig. 8). In a line graph, the data is not simply recorded; rather, it is transposed from actual space onto the space created by Cartesian coordinates in a system consisting of two parts: a superstructure of axes that creates the space, and a set of components that represents events in that space. Along the vertical axis of Hubble's graph, *KM* is kilometers per second; along the horizontal axis, *parsecs* are the unit of measurement equivalent to approximately 200,000 times the distance between the earth and the sun. Hubble's filled and empty circles and his single cross are his data points, his solid and dotted lines, his indicators of central tendency. Transposition into the space created by Cartesian coordinates transforms the data: it reveals a trend otherwise invisible or barely visible, namely the direct relationship between extra-galactic distances and velocities.

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Velocity-Distance Relation among Extra-Galactic Nebulae.

Fig. 8. Hubble's Graph. In "A Relation between Distance and Radial Velocity among Extra-galactic Nebulae." *Proceedings of the National Academy of Sciences*, 1929.

What do these patterns of lines and dots signify? For us, they are evidence of an expanding universe, Hubble's discovery; for us, his lines are more salient than his data points. But not for Hubble; for him, the data points were more salient. Because the scatter is considerable, Hubble displays interpretive caution. He acknowledges that his data support "the validity of the velocity-distance relationship in a very evident manner." Nevertheless, he refuses to speculate on the most obvious interpretation of its significance: "New data to be expected in the near future may modify the significance of the present investigation or, if confirmatory, will lead to a solution having many times the weight. For this reason it is thought premature to discuss in detail the obvious consequences of the present results" (Hubble 1929, 172–173). Even when his results were confirmed, Hubble persisted in regarding the relationship he discovered as stubbornly empirical. To him, his graph was *suggestive* of expansion; to later interpreters, it was *evidence of* expansion.

Is Hubble's line graph iconic, indexical, or symbolic? We can call it iconic so long as we recognize that the raw data is transposed in the interest of determining indexicality; we can call it indexical so long as we recognize that the causal chain between the events and the central tendency that is represented in the graph is complex and its import equivocal; we can call it symbolic so long as we understand that the symbols are the components of a cognitive system that transforms actual space into the space created by Cartesian coordinates in the interest of determining some aspect of the causal structure of the world. While X-rays and graphs like Perrin's record and transcribe, line graphs and diagrams transpose and transform. But all do so with the same purpose: determining the causal structure of the world as a calculable nexus of forces.

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A calculable nexus of forces: incorporation of all of the sciences into a single world picture

The attempt by Carnap and others to unify the sciences by reducing them to physics or to a language that was strictly observational failed; moreover, in the wake of that failure, philosophy of science has fragmented; it flourishes in apparently incompatible branches – physics, biology, mathematics, medicine. For Heidegger, however, such fragmentation is a mistake. Science is, of course, reducible neither to physics nor to a neutral observation language. Nonetheless, it is motivated by a single attitude, a common way of revealing and, simultaneously, of concealing Being. The modern life sciences are analogous to modern physics, chemistry, and geology in that they conceive of living things as machines or as the consequence of machine-like processes. As a consequence of this reduction, the modern life sciences necessarily fall short of the completeness possible in physics: "We feel that what zoology and botany investigate concerning animals and plants and how to investigate it may be correct. But are they still animals and plants? Are they not machines duly prepared beforehand of which one afterward even admits that they are 'cleverer than we'?" (Heidegger 1962b, FD 31; 1967, WT 41). In later essays Heidegger sums up: "A living thing can indeed also be grasped as a spatiotemporal magnitude of motion, but then it is no longer apprehended as living" (Heidegger 1950, ZW 73; 1977a, EWP 120).

In the modern life sciences, two fundamental questions can be asked: How does a particular biological machine work? and By what machine-like process does such a biological machine come into existence? The first question is addressed by Charles Perrault in an article on the chameleon published in 1669 in the *Journal des Sçavans.*

Perrault's two plates (fig. 9) are related as cause to effect: the structures displayed in the first plate allow us to identify the parts that make up the biological machine that is the chameleon. The second also illustrates a relationship of part to whole; in this case, the part is the chameleon, the whole, its environment; the chameleon is a machine that is itself a component of an all-encompassing machine. In each case, what is iconic is represented with indexical intent: What causes the chameleon to be a chameleon? What causes it to function effectively in its environment? For example, how does it use its tail and claws to achieve balance and mobility? For Perrault as for Heidegger, the chameleon of science, whether isolated from, or placed into an environment, is at bottom a calculable nexus of forces.

In the modern life sciences, it is also possible to ask by what machine-like process the particular machines we call living creatures come into existence. *The Origin of Species* is Darwin's answer to this question, a response embodied in the only diagram in that work (fig. 10). The diagram's vertical dimension is time; its horizontal dimension, organic diversity as it changes over time. The further up you go, the nearer you get to the present; the further apart species are, the more they have differentiated themselves from their parent species through evolutionary processes. Reading the diagram vertically, we trace descent. We see that a^1 and m^1, and a^{10} and m^{10} have the same remote ancestor A.

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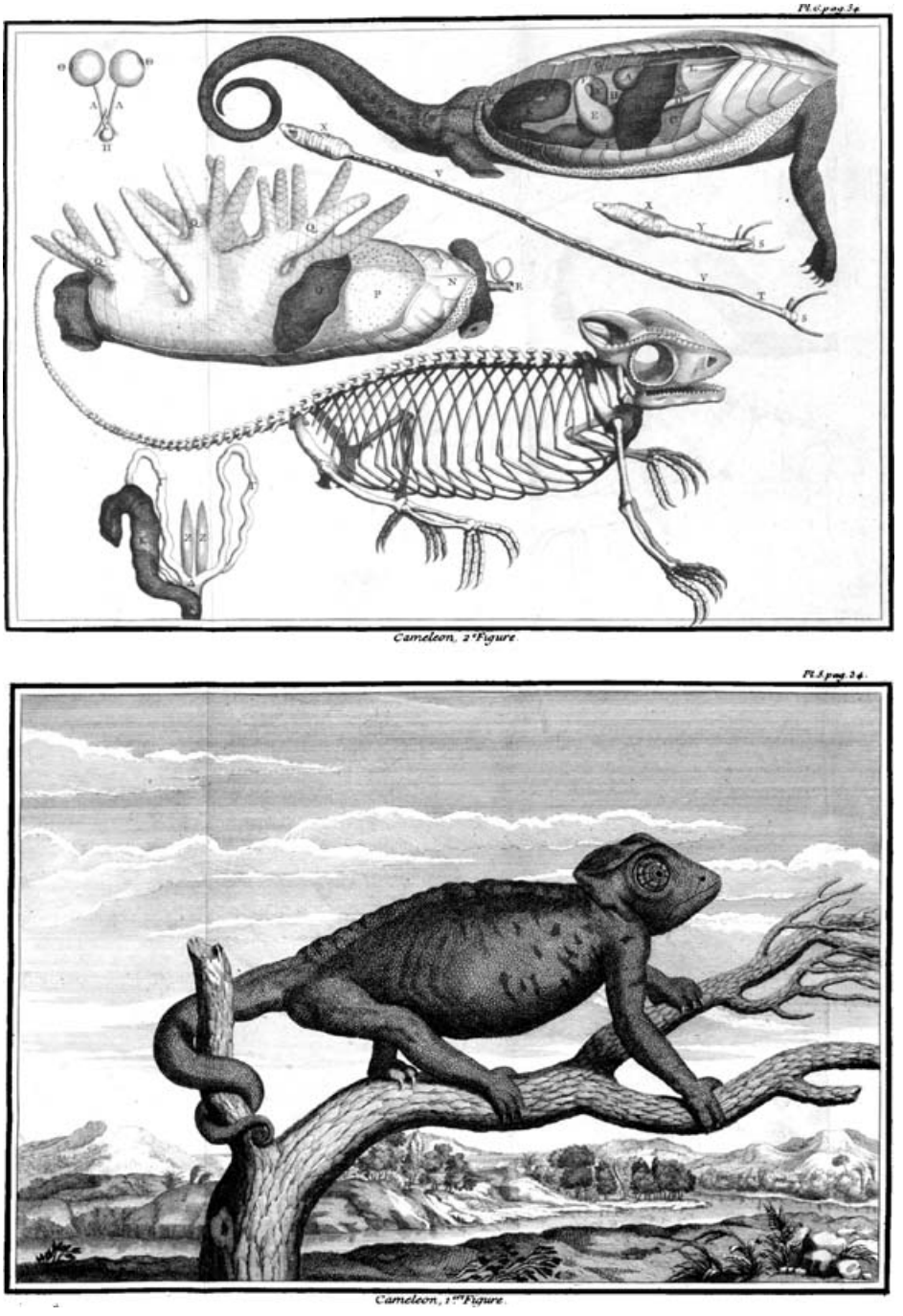


Fig. 9. Perrault's Chameleon. In "Description anatomique d'un Caméléon, d'un Dromadaire, d'un Castor, d'un Ours, & d'une Gazelle." *Journal des Sçavans*, 1669.

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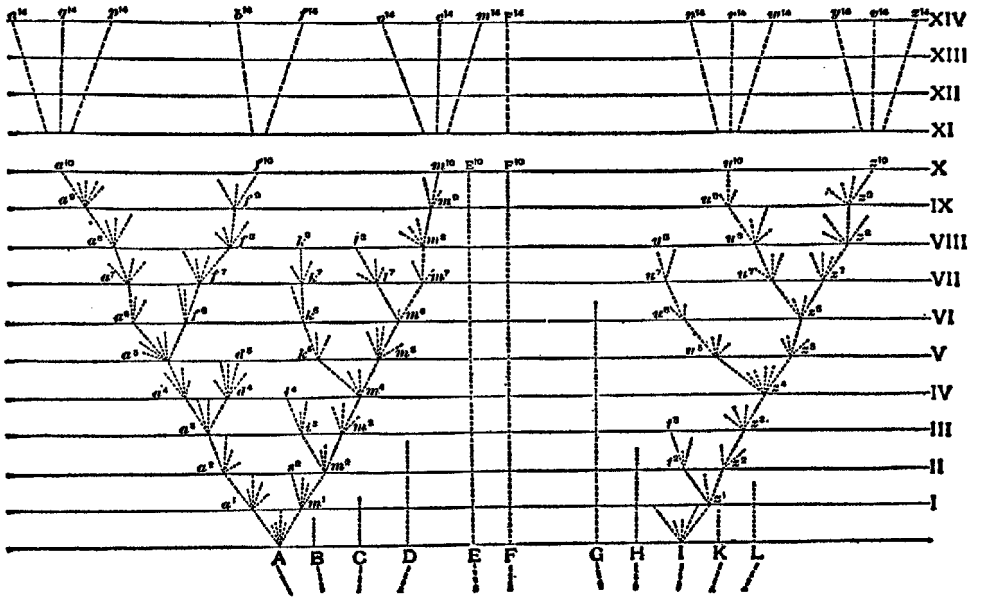


Fig. 10. Darwin's Diagram. In *On the Origin of Species*, 1859.

Reading horizontally, we see that far greater evolutionary divergence exists between the latter pair than between the former.

Extinction is also represented in the diagram – by the end of a line. Species s^2, the descendent of A, becomes extinct in Era II; species u^8, a descendant of z^4, which is, in turn, a descendant of I, becomes extinct in Era VIII. The diagram also embodies the cause of extinction, the struggle for existence. It is no accident that A, F, and I, whose ancestors are still living, were originally nearly the most divergent from each other, for the nearer species are along the horizontal dimension, the more likely they are to compete for the same territories and resources in the battle for survival; the more likely they are to become extinct. In many cases, B, C, and H, for instance, there is no evolutionary change over time, but only in the case of F do we still have a living species, a living fossil.

Darwin makes a theoretical point about the significance of the position of the numbered letters: "In our diagram the line of succession is broken at regular intervals by small numbered letters marking the successive forms that have become sufficiently distinct to be recorded as varieties. But these breaks are imaginary, and might have been inserted anywhere, after intervals long enough to have allowed the accumulation of a considerable amount of divergent variation" (Darwin [1859] 1964, 119). Despite their individuation as points, therefore, species a^1, a^2, a^3, etc., are not real; even the lines of divergence are conjectural; they are *dotted* lines. Only the processes that create divergence are real. That the diagram is static is a limitation of the printed page, a

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technical limitation; on the computer screen, the diagram would be as dynamic as the process itself. Evolution embodies an ontology of process, rather than of product.

Thus far we have seen Darwin's diagram as an icon with indexical intent, pointing to the cause of evolution as a calculable nexus of forces. But this diagram is also literally iconic of the geological record, "a succession of the successive strata of the earth's crust including extinct remains" (ibid., 124), a record of evolution. Nevertheless the geological column is, as it were, time made visible: looking at the fossil embeddings in the geological column, we are, in a very real sense, *looking* at the past. It is a past, moreover, that the first reading of the diagram allows us to understand. Viewing the geological record, Darwin says, "we find . . . such evidence of the slow and scarcely sensible mutation of specific forms, as we have a just right to expect to find" (ibid., 336).[7] Darwin's diagram, then, depicts two things simultaneously: a theory, evolution, and a fact, the geological column. But the theory and the fact are related to each other as cause to effect: properly interpreted, the geological column with its accompanying fossils is an index of a causal theory, the theory of evolution.

Scientific meaning: from the visual to the propositional

Although scientific visuals reveal the causal structure of the world, without language, that is, without the concepts that language embodies, what is revealed can neither be fully understood nor can this understanding be conveyed to others. In science, therefore, the visual can never be sufficient. Because enframing strips the world of its everyday significance, scientific visuals exist initially in a liminal state, one in which their meaning is, at best, indeterminate. To become specifically meaningful again, to become science, they must be re-contextualized in a new world, one in which the calculable nexus of forces is the overriding concern. The verbal is necessary for this process: a visual cannot tell us in what ways it represents; only language can perform these functions. Hubble's graph reveals the correlation between nebular velocity and distance only because it is labeled as such; moreover, it is only Hubble's words that endorse the possibility that this correlation might indicate that the universe is expanding. Roemer's diagram reveals the orbits of earth and of Io as a celestial clock only because it is labeled as such; moreover, it is only his words that point out the startling implication of its poor time-keeping. In science, in the end, meaning is the province neither of the visual alone, nor of the propositional alone: it is rather the consequence of the *fusion* of the visual and the propositional.

The interpretive movement from the visual to the propositional is instantiated in H. B. Whittington's article on a fossil animal retrieved from the Burgess Shale.

[7] The location of these forms and their fossil remains, it should be noted, is not their physical but their evolutionary location, not where they are found, but where, once found, they belong in the evolutionary sequence: they exist, not in real, but in conceptual space.

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Individuals of the species, *Opabinia regalis*, were "trapped alive by a moving cloud of suspended sediment, and buried as it settled out [500 million years ago]." The sediments were compacted, compressing the animals but nonetheless preserving their outer covering, alimentary canal, and, possibly, their gut passages. Despite an eventual compression ratio "greater than 8:1," the fossils were not "crushed flat" (Whittington 1975, 10–11) but were preserved in their three-dimensionality, a condition that permitted their dissection and study.

Separated from their surrounding rock, the fossils are dissected with fine chisels and delicate drills and then photographed. Photographs in two sorts of light reveal different features, as we can see by comparing figures 11 and 12. To obtain a more clearly differentiated view of *Opabinia regalis*, Whittington uses a *camera lucida*, a device that projects an image so that it can be accurately sketched. With the aid of this device, he creates the next figure, a further step in unconcealment (fig. 13). Whittington's figure is oriented left (L) and right (R), and contains such details as the eyes (o and i), the gills (g), the lobes (l), the fins (f), a reflective rectangular area (rec), and the cephalon or frontal portion (ce). Running down the center of this camera lucida sketch is the alimentary canal. With this labeling, the propositional emerges from the visual. From these camera lucida sketches, Whittington is able to reconstruct the animal itself, a further interpretive step, also assisted by labeling (fig. 14).

From his meticulous reconstruction, Whittington recreates by inference the "mode of life" of this early denizen of ocean floors, a creature only about four inches long. The words that have been italicized (other than the creature's name) trace this inferential process in the text, the move from the visual to the propositional:

> The mode of burial of Burgess Shale fossils . . . *implies* that the animals were benthonic [sea-bottom inhabitants] in habit, otherwise they were *unlikely to be* trapped by suspended sediment moving along the sea bottom. The nature and position of the compound eyes of *Opabinia regalis indicates* that they were well adapted to detect changes in intensity of light, and thus movements, in waters beside or above a benthonic animal. The frontal process is *interpreted* as having been muscular, adapted to exploring the sediment for food, trapping it, and conveying it to the mouth. . . . No jaw structures are known, so the food was *presumably* soft. Digestion *may have been* aided by diverticula of the gut, which extended into the lateral lobes of the trunk. These lateral lobes *must have been* moderately rigid (wrinkling and variations in outline in the fossils being *attributed* to post-burial compression), able to support the body on the soft substrate, and an up and down movement would both aerate the gills and propel the animal. *It may be assumed* that such movements were slow, enabling *Opabinia* to plough shallowly in the surface of the bottom mud as the frontal process explored for food. The eyes and the tail fan *would have been* just above the surface of the mud, and the blades of the fan *may have helped* to create currents over the dorsal surface of the body, aiding in aeration of the gills. Flapping movements of the lateral lobes *may have also enabled* the animal to have moved over the substrate, swimming feebly. *If* such movements were in the form of a metachronal [sequential] wave along the body, the swimming powers *would have been*

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Fig. 11. Opabinia Part. H. B. Whittington. Fig. 9 in the original. In "The Enigmatic Animal *Opabinia Regalis,* Middle Cambrian, Burgess Shale, British Columbia." *Philosophical Transactions of the Royal Society*, 1975.

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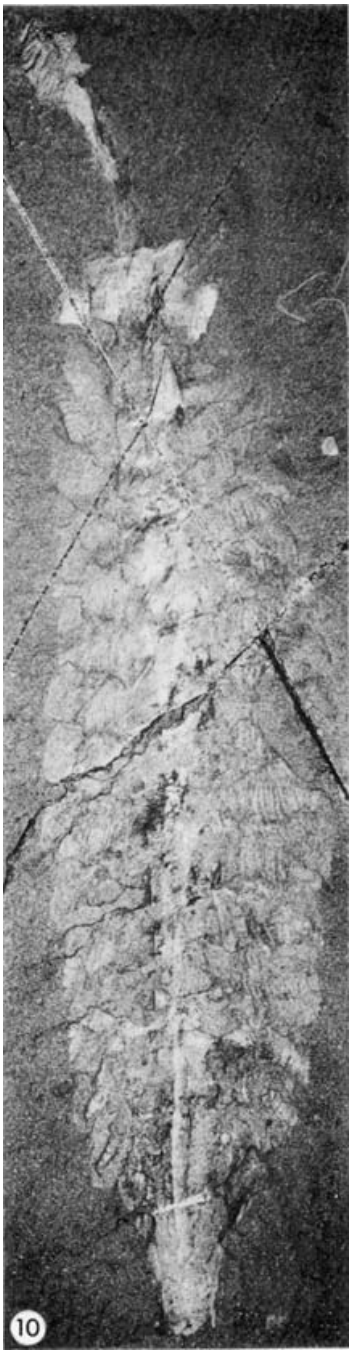


Fig. 12. Opabinia Counterpart. Fig. 10 in the original. In "The Enigmatic Animal *Opabinia Regalis,* Middle Cambrian, Burgess Shale, British Columbia." *Philosophical Transactions of the Royal Society*, 1975.

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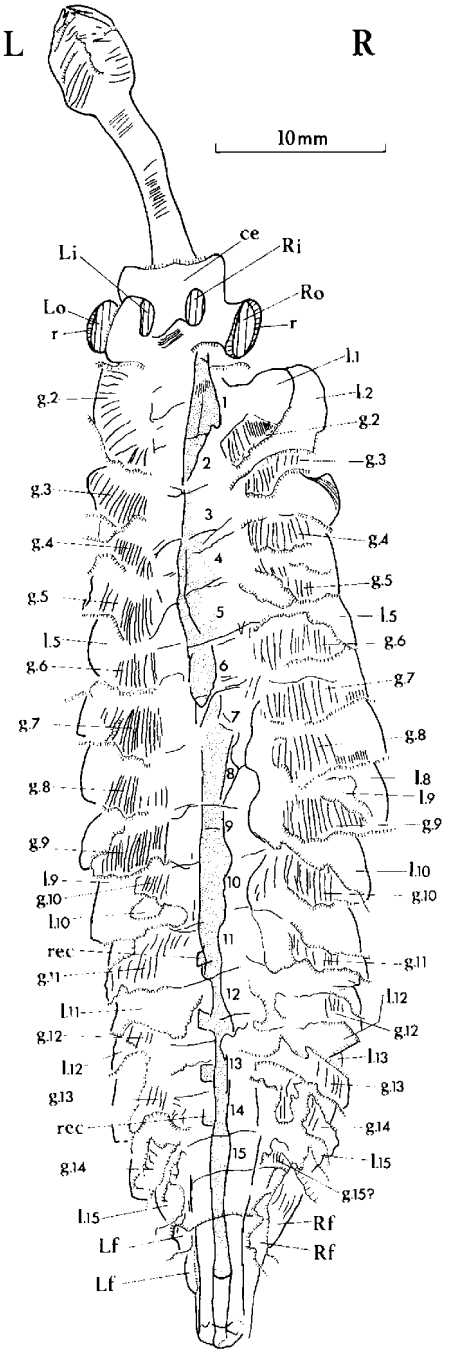


Fig. 13. Opabinia Camera Lucida Sketch. Fig. 12 in the original. In "The Enigmatic Animal *Opabinia Regalis,* Middle Cambrian, Burgess Shale, British Columbia." *Philosophical Transactions of the Royal Society*, 1975.

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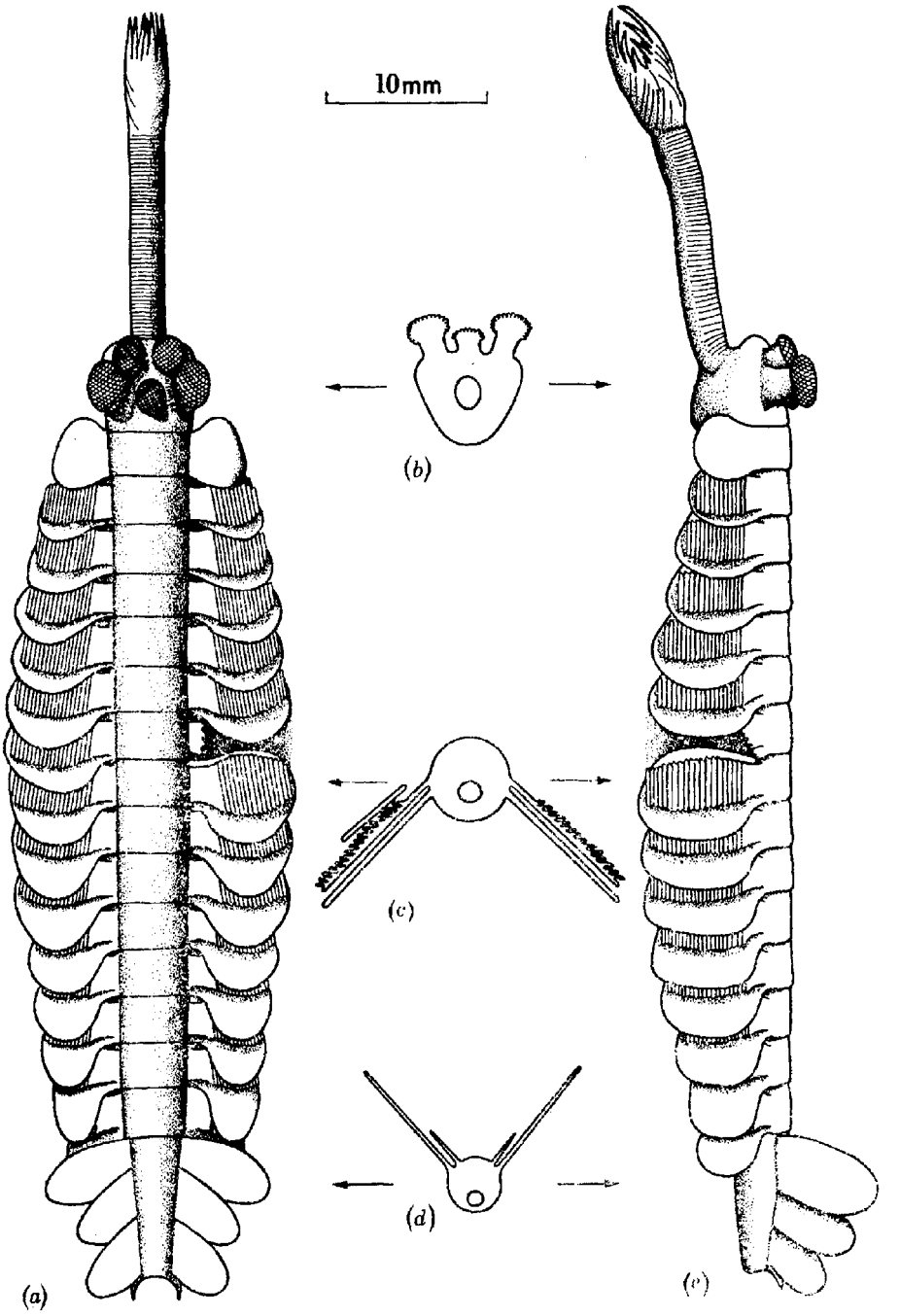


Fig. 14. Opabinia Reconstruction. Fig. 82 in the original. In "The Enigmatic Animal *Opabinia Regalis,* Middle Cambrian, Burgess Shale, British Columbia." *Philosophical Transactions of the Royal Society*, 1975.

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> somewhat stronger, and the tail fan *could have been* used in steering. The fossils do not *suggest* more than a limited flexibility of the trunk, so that swimming by a body wave *does not seem to have been possible*. (Whittington 1975, 39-40; Plate II; Figures 12 and 83; emphasis added)[8]

Whittington's article is a text-book example of the synergy of the verbal and the visual in bringing a long-extinct creature before our eyes as the product of a calculable nexus of biological and geological forces. His methods show us the futility of the "high and often unrelenting empiricism [of the Academy of the Lincei] seemingly devoid of the kinds of discrimination necessary for theory and a more systematic view of the world," and the prescience of one of its members, Federico Cesi, that "sight was essential for good science, but sight alone could never be sufficient," his realization that what was "at stake finally, [was] the ordered, mathematically determinable structure of all things" (Freedberg 2002, 67, 180–81).

Whittington's two photographs display the fossil itself; they show what he had to work with initially. Figure 13 combines fossil part and counterpart in a meticulous reconstruction. The final set of drawings differs from the initial reconstruction in that it gives a sense of how the creature looked when it was alive. In the accompanying verbal description, Whittington does not merely depict, he actually evokes through inference the animal as it lived and moved on the bottom of the sea. His evocation constitutes an explanation of the fossil remains his science has just unconcealed; it reveals this fossil as the consequence of a calculable nexus of geological and biological forces. In his paper on *Opabinia regalis*, then,Whittington recapitulates a Heideggerian progress: the propositional emerges from and eventually merges with the visual.

Conclusion

In the third book of *Gulliver's Travels*, Jonathan Swift abandons his tight narrative and indulges forthrightly in broad satire. In his account of the Grand Academy of Lagado – read the Royal Society – he is particularly merciless. Among his targets are the attempts to reform the language. He takes as his particular example Sprat's pronouncement that scientific communication must "return back to the primitive purity and shortness, when men delivered so many things in an equal number of words" (Sprat 1667, II, xx). His wicked lampoon takes this pronouncement literally, and has as its climax two "sages" exchanging views without the benefit of natural language, both burdened with heavy bags of "things" that they laboriously pass to and fro (Swift [1726] 1999, 190–91).

[8] A computer simulation would enhance this description; it might be thought that such a visualization would also substitute for this description. But this would be an error. A computer simulation could not represent the process of inference by which it was achieved.

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Swift has been proven right: science has found natural language indispensable to the creation of meaning. But Swift has also been proven wrong. Artificial languages, such as those of mathematics and logic, though ultimately they depend on natural language, *are* more perspicuous, the notation that Leibniz invented for his calculus being a good example. Equally significant, science has found that "things" (in the form of scientific visuals) are as indispensable to the meaning it creates as is natural language. Heidegger explains why in science the verbal and the visual must collaborate in the creation and communication of meaning. If Heidegger is right, however, these partners, though equal in practice, are not equal epistemically: the visual is importantly prior.

Abbreviations

BT Heidegger, 1962a, *Being and Time.*
EWP Heidegger, 1977a, "The [Era] of the World Picture."
FD Heidegger, 1962b, *Die Frage nach dem Ding.*
FT Heidegger, 1954a, "Die Frage nach der Technik."
QT Heidegger, 1977b, "The Question Concerning Technology."
SR Heidegger, 1977c, "Science and Reflection."
SZ Heidegger, 1972, *Sein und Zeit.*
WB Heidegger, 1954b, "Wissenschaft und Besinnung."
WT Heidegger, 1967, *What is a Thing?*
ZW Heidegger, 1950, "Die Zeit des Weltbildes."

Acknowledgments

I would like to thank the two anonymous readers of *Science in Context*, and my colleagues, Arthur Walzer and Carol Berkenkotter, for their careful reading of earlier drafts of this essay.

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