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VISUAL CULTURES OF SCIENCE

Rethinking Representational Practices in Knowledge Building and Science Communication

Edited by Luc Pauwels

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1

A Theoretical Framework for Assessing Visual Representational Practices in Knowledge Building and Science Communications

Luc Pauwels

The multifaceted issue of visualization in science basically involves the complex processes through which scientists develop or produce (and communicate with) imagery, schemes, and graphical representations, computer renderings, or the like, using various means (ranging from a simple pencil on paper to advanced computers or optical devices). Therefore, not just the result, but also how it was attained (i.e., the implicit or explicit methodology in the broad sense of the word) and indeed the subsequent uses to which the result is put should all be scrutinized as to their impact on the nature of what is represented visually and the ways in which this representation can be employed. Visual representations in science differ significantly in terms of how they relate to what they purport to represent (i.e., their representational and *ontological* status), the means, processes, and methods by which they are produced, the normative contexts involved, the primary purposes served, and the many ways in which they subsequently are used and combined, to name but some of the more crucial aspects.

Because of the diversity of appearances and applications and the broader contexts in which they need to be placed (e.g., scientific theory and traditions, culture, media, and technology), it is indeed a challenge to make generalizations about the uses and functions of visuals in scientific discourses. This may explain the remarkably few systematic attempts that have been made at devising a common, by necessity rather basic, framework for increasing insight into this complex domain. This chapter seeks to present such a general framework for looking judiciously at visual representations in the context of scientific endeavors. It discusses a number of critical aspects that should be considered when producing, reading, or (re)using visual artifacts. It will not be able to do justice to all aspects of and perspectives on this complex problematic but might at the least help to bring some basic structure into it. The purpose of this model is to stress that the sciences, despite their differences, in fact do have a lot in common—both difficulties and solutions—and that bringing them together may illuminate future practice.

1. The Varied Nature of the Referent

The array of objects or referents of visual representations in science is very broad and of a highly heterogeneous nature. Visual representations in science may *refer* to objects that are believed to have some kind of material or physical existence, but equally may refer to purely mental, conceptual, abstract constructs and/or immaterial *entities*.

Material or physical referents may have visual characteristics that are *directly observable* to the human eye (e.g., various types of human interaction, the external structure of animals, trees, etc.). On the other hand, there are objects and phenomena with aspects that *only become visible with special representational means and devices* (e.g., they can be observed only using special techniques or instruments such as high-speed photography, satellite image transmission, a telescope, a microscope, or an endoscope). These aspects may be too fast (e.g., an explosion, eye movements), too slow (e.g., transformations in a living organism), too big (e.g., stellar configurations), too small (e.g., microscopic organisms), too similar (e.g., color of vegetation), or too far away (e.g., planets) for the human eye to discern, or they may be hidden (e.g., organs of a living body) or inaccessible unless destructive course of action is taken (e.g., by dissection of an organism, creation of a cross section of an object, excavation of remains). Furthermore, physical objects or phenomena may not have visual characteristics as such and still be *translated from a non-visible state* (e.g., sound waves, thermal radiation) *into visual representations* using special devices.

Representational practices in science often do not seek merely to *reproduce* visual or non-visual phenomena but also to provide *visual data representations* (e.g., charts) of aspects of these phenomena based on measurements of some kind (length, weight, thickness, resistance, quantity, temperature, verbal responses, etc.). In the latter cases, *data* are derived from or constructed on the basis of an observed reality and subsequently represented in a visual form that allows one to discern changes or

see relationships more clearly. While the resulting representations are based upon empirical observation or interrogation of the field, they are not *reflections* of visual natural phenomena. They are rather visual representations of observations in the physical world that are not necessarily visual in nature. In other words, what is represented are not physical objects or phenomena, but *data* that are constructed by observing aspects of the physical world. The relationships among the data and their representations are much more abstract/arbitrary and conventional, though some aspects may also be *motivated* or iconic (i.e., they may bear some resemblance to the referent). For example, graphical representations of the evolution of the birth rate within a particular population over a certain period of time, temperature fluctuations during one month in summer, or the number of murders per state do not necessarily entertain a visual iconic or indexical relationship with a physical or material referent, as often there is none. Instead, these data representations may have a *mental* referent as far as the source is concerned, since the representations are not so much *depictions* of phenomena in the real world as conceptual translations of aspects of it. Yet, they are based at least in part on quantitative or qualitative aspects of an observed *reality* of some kind and thus are not purely invented or products of the imagination.

The referent of a representation may be even more *immaterial and abstract* in nature: for example, representations that primarily seek to visualize relations among observed phenomena, hypothetical relationships, postulated phenomena (e.g., black holes) or effects, and even purely abstract concepts. The referent of such representations may become an almost purely mental construct that has no *pre-existence* in the physical, historical world whatsoever. Nonetheless, representations of these kinds of referents may play an important role in understanding or influencing that world.

Finally, it should be noted that many representations in science combine several of the abovementioned aspects and thus have *different referents*. Certain aspects of the representation may, for example, refer in an iconic way to an observed visual reality (e.g., it might mimic its shape or color) and at the same time include conceptual structures (such as metaphors) or symbolic elements (arrows, markers, colors, shapes). An edited film will refer iconically to the depicted subject matter (i.e., it will *reflect it* to a certain extent), but at the same time it might allow scientists to express their vision or theory by means of the manner of recording and subsequent editing processes. In fact, as is argued in chapter 6, mimesis without expression is virtually impossible. At the root of every presentation of fact is an implicit or explicit theory, a particular way of looking. In fact, visual representations may not only refer to the material world or to an

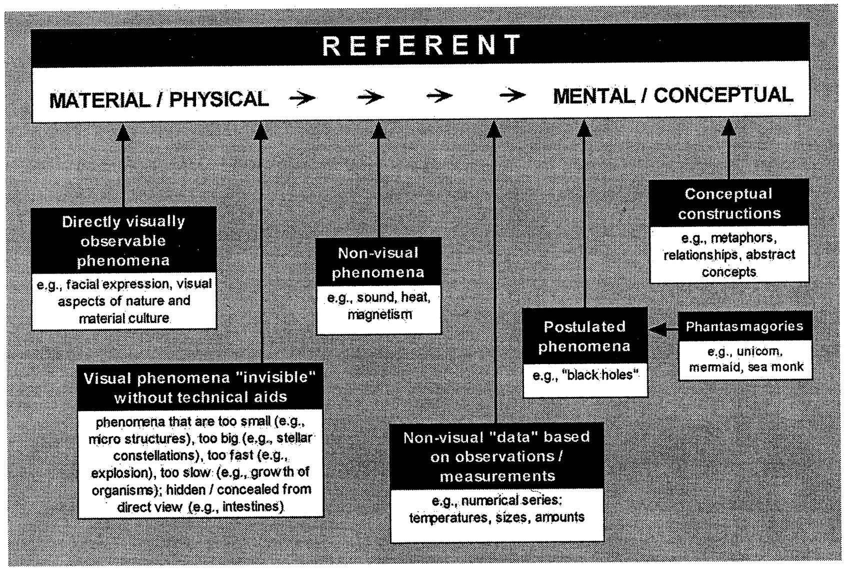

Figure 1.1. The divergent nature of the referent, from material existence to mental construction.

abstract or imaginary world but also may refer to a *possible world*, as is the case when scientists perform simulations to get an idea of what might happen when combining such and such parameters or phenomena.

This concise taxonomic preamble with respect to the nature of the referent already indicates the wide variety of material and immaterial *things* that a visual scientific representation, be it static or dynamic, may *refer* to. But I also have touched implicitly in this brief introduction upon the diversity that exists with regard to types of translation processes and actors in the production cycle, as well as the different purposes and intents of representations and specific contexts of use. The presentation and discussion of the complex interplay of these aspects constitutes an analytical framework for visual representations and related practices in the sciences.

2. Representational Production Processes: Social, Technological, and Cultural Aspects

Inscription, Transcription, Invention, and Fabrication

Every *representational* process involves a translation or conversion of some kind; a process of inscription, transcription, and/or fabrication

whereby the initial source (phenomenon, concept) is captured, transformed, or even (re-)created through a chain of decisions that involves several actors (scientists, artists, technicians), technological devices, and normative settings. This complex process of meaning-making has an important impact on what can be known and how, on what is revealed or obscured, and on what is included or excluded.

The ontological relation between a representation and its referent is always somewhat problematic even with so-called *automated processes*. However, all types of translational processes are not problematic to the same degree nor in the same sense. It is therefore not very useful to challenge iconicity in general and thus to ascribe to all types of representation a similar degree of arbitrariness. Also, the use to which a representation is being put constructs its representational status, at least in part.

As I have argued in the previous section, the divergent nature of the referent in science prefigures the crucial importance of the equally divergent processes of producing a visual representation. These processes not only involve technical issues but also encompass important social and cultural aspects. Obviously, technology and each of its products are part and parcel of culture (i.e., they are both a cultural product or *result* and a cultural actor or *force*), both in a broad cultural and a more restricted sub-cultural sense (e.g., scientific disciplinary practices and purposes), and they embody specific norms and values. For example, the specific look and the functionality of a photographic camera (i.e., dominance of the center of the frame for both exposure and focus) to some extent reveals what its inventors and subsequent developers valued the most and what kind of applications they primarily had in mind (e.g., portraits). But apart from the characteristics of the instrumentation, which are to some degree a result of cultural processes as well, a host of other social and cultural influences at the moment of choosing and selecting the objects and samples also have an important impact on how the representation will appear as well as on the purposes it may subsequently serve.

Analyzing the Social and Cultural Setting: Division of Human Labor and Different Normative Contexts

Barbara Rosenblum, in her sociological study of photographic styles, demonstrates quite convincingly how the "look of things," in particular the typical appearance of press, art, and advertising photographs, are to a significant degree a function of social, technological, and cultural factors and constraints that are connected with their creation. Her research into these areas indicated that "photographic styles are directly correlated with systems of production and distribution." Her observations of news photography as a highly conventionalized and comparatively homogeneous "system of images" that is generated within a bureaucratically coordinated system (Rosenblum 1978, 111) provide some interesting parallels with at least some of the ways in which imagery is produced in scientific contexts. After all, the division and standardization of labor, technological constraints, professional ethics, time pressure, as well as economic factors, all play a significant role in their creation, look, and value. Drawing on several fields of expertise and modes of practice, Charles Goodwin (2001, 157) argues credibly that an ethno-methodological perspective provides an essential complement to any study of visual representation that seeks to go beyond textual borders and into the broader contexts of production and uses.

Sociologists of science have studied the complex interactions in a laboratory setting where science is being *produced* (Goodwin 2001; Latour and Woolgar 1979; Lynch 1985b), an approach that yields insight into how an object of inquiry is selected, delineated, and *prepared* to fulfil its role. Lynch has looked at the laboratory setting and the processes by which natural objects are visualized and analyzed. Preparatory procedures that turn the object of investigation into a "docile object" fit to be studied according to the established methods and mores of science, the instrumentation and the laboratory set-up all challenge the idea that scientific visualization provides an unproblematic or uncompromising "window" onto the natural world (Lynch 1985b, 43–44). Similar processes are at work when scientists make observations in the field, as objects likewise are selected and prepared to be subjected to scientific practices or made to participate in data-generating procedures. Not only natural scientists, but also social scientists try to produce "docile objects" through sampling techniques, pre-structured questionnaires, and statistical operations. What cannot be measured, or only very inconclusively, is often overlooked and assumed to be non-existent. The *picture* that is obtained by the established procedures often is presented as a reliable and valid reflection of a broader phenomenon or population. Even in more qualitative types of visual research, such as anthropological filmmaking, the crucial importance of the process of data gathering and processing is recognized, and fierce debates continue to rage about what types of expertise should be combined in the scientist, what are (in)appropriate forms of collaboration with professional filmmakers and/or editors, how

the *field* can be involved actively, what purposes a scientific film may fulfil, etc. (Pauwels 1996).

Furthermore, the issues of research funding, academic recognition, peer relations, and societal trends must all be taken into account if one endeavors to reveal and explain the processes that lie at the heart of particular visual representations of facts or ideas. They likewise may influence what is selected and how, and the way in which it is processed.

The Varied Nature of Visual and Non-Visual Transcription

There is a fairly significant though not exclusive or unconditional relation between the nature of the referent and the processes through which a representation is or ought to be produced.

Obviously, *conceptual constructions* that have no material, let alone visual, substance cannot be recorded automatically or according to standardized and repeatable processes (for example, mental images cannot be photographed or scanned electronically), as they are the result of multiple intentional acts that, first and foremost, require a suitable production technique for such highly intentional activity (e.g., pencil and paper or a computer drawing package). The involvement of the originator of the idea is paramount, and a demanding process of translating a mental image into an inter-subjective visible image is required. Aspects or dimensions that cannot in any way be visualized or verbally described are in fact lost to science.

Objects or phenomena that are *visible to the human eye* through direct observation, on the other hand, can be captured by representational devices such as a photographic camera that will produce detailed representations characterized by uniform time and a continuous space. This may result in a kind of *indifference* (some might say *objectivity*, though this may be too burdened a term to use), since all elements and details are treated equally (even though photographers have ways of foregrounding or emphasizing certain aspects at the expense of others, such as through the choice of lens, film, filters, lighting, framing, viewpoint, etc.). However, directly observable phenomena also can be represented through more manual techniques, using simpler media, such as pencils and brushes, which require much more *intentional* series of acts by humans (draftsmen, illustrators) and which produce imagery that do not have a uniform time (in fact quite some time may pass during the creation of the different parts of the representation) and that are not bound by continuous space or a uniform use of scale.

Every representation requires some kind of device or medium. Yet it is useful to make a distinction between mediation processes that are highly automated, or *algorithmic* processes (e.g., photography), and more manually and intentionally performed activities (e.g., hand-drawn or driven representations). However, these are not absolute categories and it is better to think about this useful distinction as two extremes of a continuum. Moreover, current digital technologies have blurred the dichotomy between *machine-generated* and *handmade* imagery and increasingly have allowed for more complex combinations of the two (for instance, digital photographs that can be manipulated at will with the aid of sophisticated software).

The process whereby one works from a *directly visible referent* to a *visual representation of it* would appear to be the most straightforward, but even then a great variety of techniques are available. Moreover, even the more commonly applied techniques have their intricacies, which are easily overlooked. This is true of relatively simple and ubiquitous techniques, including photography of directly observable phenomena, where one often has the advantage of being able to compare the referent (the object or phenomenon with a material existence) and the depiction (a drawing or photograph). However much such devices may differ in terms of the manner in which they *translate* an object or phenomenon into a record of it, it is important to note that both the source or the referent (the natural object or phenomenon) and its representation are *visual* in nature and are respectively captured and constructed by methods or processes that are essentially visual as well. In such instances, there is at least the theoretical option of comparing the source and its representation in order to assess to what degree and in which respects they resemble one another. Thus, a *check of correspondence* can be performed, albeit only to a certain degree.

A much more complex translation process occurs when the referent is visual and physical in nature (though often hidden from direct observation), while the *intermediate steps are not based on reflected visible light* waves. This is the case, for example, when ultrasound scans or X-rays are used: In these instances, it is not light that is reflected by the object that is recorded, but a reaction of other types of *invisible* waves to some characteristic or aspect (such as density) of the structure of the referent. These translations, while equally *indexical* in nature, typically require a more cumbersome process of decoding and calibrating (see, for example, Pasveer 1992) and they do not allow a simple check of *visual correspondence*.

Radiologists, for instance, need to learn how to *read* these images and even then they may differ on how a particular one should be interpreted.

If the translation process is not visual or if the referent is inaccessible or invisible to the unaided human eye, one has to rely on—and thus transfer authority to—the "machine" (Snijder 1989) in order to chart often unknown territory. In such cases, one has to be particularly aware of the possibility that one is looking at *artifacts of the instrumentation,* that is, objects and effects that are generated by the representational processes themselves and that do not refer to anything in the outside world or at least not to the phenomenon that is under scrutiny. In many data-generating processes, it is not always easy to differentiate *noise* from *data.* Artifacts or effects thus may be attributed erroneously to the outside world while in fact they are produced standardly by the instruments or as a result of technical failure. Moreover, an atypical representation also may result from an unexpected and unaccounted for event or coincidence in the physical world.

So, especially if the referent is of an uncertain nature, the problem of artefacts of instrumentation may arise. This may be the case when the existence of the referent is postulated rather than confirmed by fact and the process of representation serves the purpose of providing such evidence, or when complex instruments are being used, or when aspects of reality can only be seen through the instruments, that is to say, as a *representation.* But even with very realistic renderings of directly visible objects (e.g., simple camera images of directly observable phenomena), one should be wary of the possibility of *effects* induced by the instrumentation. Such effects can present themselves to the uninitiated eye as qualities or traits of depicted objects (color, shape, spatiality) while in fact they are merely properties of the instrumentation (e.g., the extremely foreshortened perspective when using telephoto lenses makes objects appear much closer to one another than they are in reality; internal reflections may produce flare and ghosting; etc.).

In a similar way, scientists should be aware of the possibility that important aspects of the referent might not be captured by the instrumentation (e.g., because of an inadequate resolution or insensitivity caused by a limited spectral range) or might mistakenly be weeded out as noise.

Instruments, in addition to capturing or recording data, invariably both reduce (or lose) data and tend to mold (and add) data in a particular way. These two phenomena in themselves should warn against a naïvely realistic view of the merely technical aspect of representation.

Technically sophisticated instruments that produce representations or images in a highly automated and standardized way (such as cameras and scanning devices) are generally thought of as the most suitable for scientific purposes, as they produce coherent, reliable, and repeatable representations with a predetermined level of detail. Moreover, they tend not to rely too much on personal judgement or skills in the process of image generation, unlike manual techniques such as drawing (though the interpretation of such representations may still require a lot of personal judgement and experience!).

However, in some cases more intentional processes and products may be far more convenient. This is true, for instance, if the depiction is *too detailed* for the intended purpose. This may be the case when using a highly automated and *indifferent* process such as a camera recording. Such a recording can be indifferent in the sense that all visible elements in front of the lens receive the same treatment, irrespective of whether they are relevant to the researcher. Thus, the essence of the recording may be obscured by unneeded, distracting, or irrelevant detail that can prevent insight. Furthermore, intentional processes allow a much swifter combination of *different types of signs (iconic, indexical, and symbolic) and levels of signification.* Consequently, they may yield a more functional expressive presentation of fact and vision. A third important consideration is that intentional processes may provide a much needed *synthesis of features* rather than a simple transcript of a particular (snapshot-like) instance of a phenomenon.

For instance, ornithologists who use imagery to determine the species of a particular bird encountered in the field may be better off with well-crafted illustrations of a number of similar-looking species—such as a colored drawing that contrasts a heron (*Ardea cinerea L.*) and a purple heron (*Ardea purpurea L.*). After all, they can derive from such a drawing how the two birds differ *in general.* Color photographs, on the other hand, necessarily show a particular specimen of each type of heron in a particular stage of its development and photographed against a particular background, in particular light conditions, from a particular angle. This photographic *particularity* may be less helpful in determining the species of an individual bird in the wild. On the other hand, purposefully simplified representations and abstractions may instill some misconceptions in people's minds if they are not duly communicated or if they are used for other than the initially intended purpose. For example, medical students

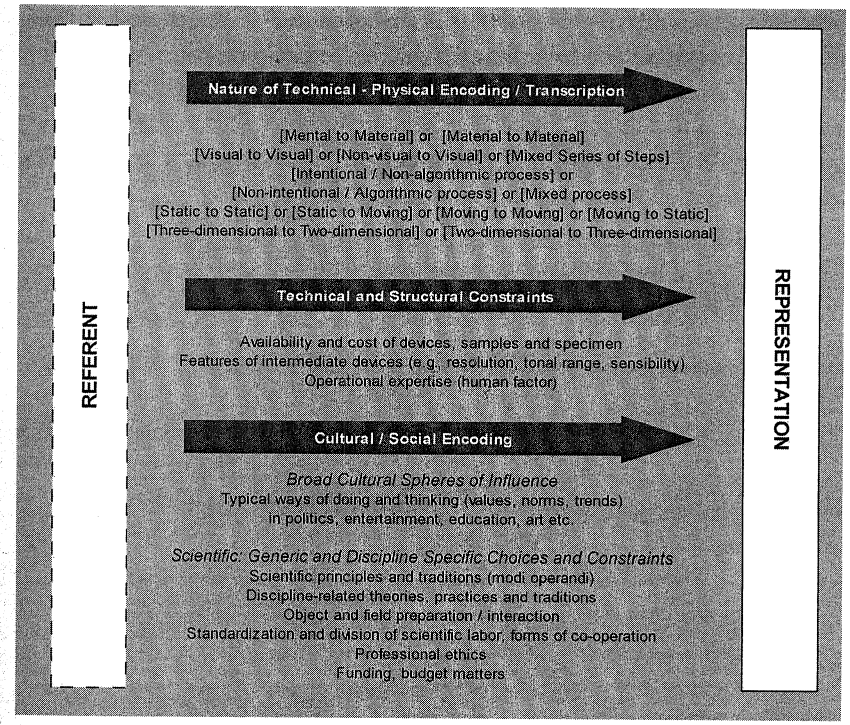

Figure 1.2. Determining aspects of the production/translational processes on the appearance of the visual representation.

may be baffled by the visual difference between stylized and simplified anatomical drawings of heart, lungs, and vascular system in their introductory courses and the *real thing.* Similarly, engineering students may be surprised by the difference between a highly stylized drawing of engine wiring and the three-dimensional reality of a dismantled engine that needs reassembling.

Scientific illustration as a sub-discipline of science is an interesting example of a specialization that has evolved in recognition of the fact that both scientists and artists in general lack the skills to produce renderings of birds, human anatomy, or complex technical artifacts with the required level of detail and generic faculties. Using artists who are very skilled in drawing but largely unaware of the exact purpose of the illustration inadvertently will produce imagery that may thwart that purpose. For example, they may make "corrections" according to their own aesthetic insights, or provide too much unnecessary detail, or fail to highlight elements properly that do not stand out very well in reality because they are buried in other visual stimuli but that are nevertheless central to the purpose. Scientific illustrators, on the other hand, need to be well-versed in both the art of illustration and in specialized fields of science. They are trained to have a thorough and fully integrated knowledge of the subject matter or concepts that they are asked to draw and of the exact scientific and didactic purposes their products need to serve.

3. The Visual Product: The Impact of Medium and Execution

Cultural Impact on Style and Use of Media

Visualization obviously results in a product that can be *seen:* a graphic representation, a photograph, a computer rendering. The term "representation" in this chapter is restricted to what in "social studies of science" is commonly referred to as "inscription" (Latour 1987; Roth and McGinn 1998) as some authors feel that "representation" as a general term is rather ambiguous. However, this should not be the case if one requires that a visual representation has a material substance that is intersubjectively available as a *social object.* Mental images then, have no material and intersubjective character and therefore will not be called representations here. (They may, however, be the referent of a representation.)

The products of a visualization process emanate the characteristics of the (final) medium or successive operations as well as the features of the particular application or instance: the selections and choices of what and how to depict. The end medium or medium of presentation has an important impact on the final appearance of a visual representation. But while each medium has a number of preset characteristics, within each medium there is almost always a great variety in the manner in which a particular referent may be represented (mimetically and expressively). This choice and combination of specific formal options henceforth will be referred to as the "style of execution." The style of execution is only partly determined by the medium. The notion of a wide variety of styles within the same medium is illustrated easily by divergent painterly traditions such as Cubism and Hyperrealism. Similarly, scientists may choose a variety of methods and techniques (ranging from realist to extremely stylized to metaphorical or even phantasmagoric) for depicting a particular subject or idea. These variations in style have to do with genre conventions, cultural schemata, scientific traditions, specific circumstances of the production process, skill, preferences and idiosyncrasies of the maker, as well as

the specific purposes the representations need to serve. To complicate matters further, various media and styles may be combined in a particular representation, lending it a highly hybrid character.

Even if the referent is a phenomenon that is accessible through direct observation, this is still not a guarantee for a *faithful* or reliable reproduction, especially if a non-mechanical process such as hand-drawing or painting is involved. This is particularly true if phenomena are drawn from memory after a brief and perhaps exciting encounter (for instance, the early drawings of newly discovered animals). For representations based on first encounters or limited study, it is unlikely that even the scientists know to what extent their representations have a rule-like (general) as opposed to an exception-like quality (deviant). Even if memory is not the major obstacle, perception is always colored by prior knowledge of other phenomena, drawing conventions, cultural representational schemata, matters of skill, and mental processes. The human mind, as Gestalt psychologists revealed, seems very eager to fill in the gaps and to make us see what we want to see. Art historian Gombrich provided a textbook example of this when he commented on Dürer's famous woodcut of a rhinoceros: "He had to rely on second hand evidence which he filled in from his own imagination, coloured, no doubt, by what he had learned of the most famous of exotic beasts, the dragon with its armoured body" (Gombrich 1994, 70–71). But even drawings that are claimed to have been made "from life" ("sur vif"), such as Villard de Honnecourt's *Lion and Porcupine,* may not provide us with depictions that are as faithful as the medium allows, but can be highly ideosyncratic or artistic renderings, which in de Honnecourt's case included a quirky, stylized lion that would better serve heraldic purposes than (naturalistic) representational ones. Gombrich concludes that the claim that it was made "from life" clearly must have had a different meaning at that time (about 1235): "He can have meant only that he had drawn his schema in the presence of a real lion" (Gombrich 1994, 68). In this same classic of art criticism, Gombrich provides another remarkable example of the impact of cultural schemata on the style of a representation when he comments on a strangely oriental-looking illustration of Derwentwater in the English Lakeland by Chiang Yee:

> We see how the relatively rigid vocabulary of the Chinese tradition acts as a selective screen which admits only the features for which schemata exist. The artist will be attracted by motifs which can be rendered in his idiom. As he scans the landscape, the sights which can be matched successfully

> with the schemata he has learned to handle will leap forward as centres of attention. The style, like the medium, creates a mental set which makes the artist look for certain aspects in the scene around him that he can render. Painting is an activity, and the artist will therefore tend to see what he paints rather than to paint what he sees. (Gombrich 1994, 73)

Visual Representational Latitude: Coping with Controlled and Uncontrolled Variation in the Depicted and the Depiction

Though visual media and techniques provide many unique advantages in representing the physical world and in expressing scientific ways of thinking, as soon as a certain level of abstraction or generalization is needed—an essential facet and phase of many scientific undertakings—some distinctive problems may arise.

Verbally, for instance, one can state that a certain bird species may have three to seven spots on its wings. However, when producing a visual representation, one inevitably must draw a definite number of spots. Visuals, unlike verbals, do not offer the option of indicating a range, say "from three to seven." Instead, a choice needs to be made out of the five possibilities when representing in a single drawing a species that exhibits that amount of variation. Moreover, if a photograph is used, one is even forced to show a particular specimen of the species (or a series of photographs of different specimens), of a particular age and sex, and in particular circumstances (habitat, weather, time of day, season). Neither intentional nor more automated (algorithmic) visual images can in themselves express in a simple way the variation (in shape, color, amount) one may expect to encounter in the real world, nor can they fully explain the connections among the particularities of the representation (the variation in the depiction) and what they seek to refer to (the phenomenon and the different forms it can assume in reality).

This multifaceted problem of different types of justified or unjustified variation in scientific representations, combined with both the variation that exists within the species or phenomenon that is depicted and the variation in the depiction of certain phenomena or ideas, could be termed "visual representational latitude." This latitude will be determined partly by the capacities of the medium applied (e.g., intentional versus algorithmic media) in coping with the variation observed within the depicted phenomenon or process, but more importantly by the *manner* in which

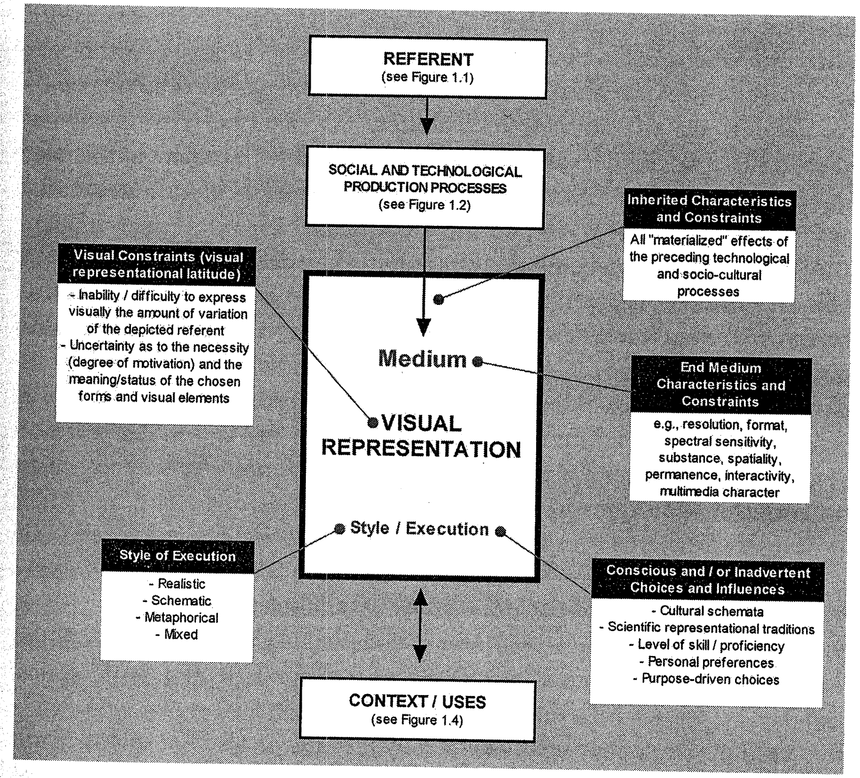

Figure 1.3. Inherited, medium-related, and execution-specific characteristics and constraints of visual representations.

that medium is used, including the stylistic options it offers, the scientifically motivated choices and the various *liberties* that producers allow themselves. The "room for maneuver" or representational margins may or may not be purposeful, functional, and understood.

Visual representational latitude, therefore, is not just a producer's (or sender's) problem, that is, it is not just a matter of deciding how to express variation, of choosing the right level of iconicity or abstraction for a specific purpose. It is also a user's (or receiver's) problem: What kind of variation is to be expected in the real world, and which elements in this particular representation are *motivated* by a perceived reality, and which others are due to specific, intentional, or unintentional choices of the producer, limitations of the medium or larger production context? To what extent is every choice to be interpreted as "necessarily so" or as just "one way of putting it"? If, for instance, a physical phenomenon is depicted as consisting of a core with, say, twenty-three particles revolving around it, one is still uncertain whether this exact number of particles is a unique and thus determining trait of the phenomenon or whether the person who produced the diagram merely meant to indicate that *many* particles are revolving around the core. Similar questions could be raised with respect to the relative distance of the constituting parts of the drawing, their scale, color, and shape, etc.

Verbal comments (e.g., in the form of an extended *legend*) are one way of making sure that users know what they are looking at, what codes are being used, what semiotic variation is being employed, and what representational claims are put in effect by the representation. Another way is to develop further a visual language of scientific representation, which in a sense restricts the ways in which visual elements may be employed but at the same time enables a more visual and less ambiguous form of information transfer and expression.

4. Types and Contexts of Use: Matters of Encoding and Decoding

Representational Constraints

Representations cannot serve adequately just any purpose or intent. Various significant relationships exist between the type of referent, the production process, the medium, and the types of uses and claims that can be attached to them. Visual representations must have the necessary *properties* to fulfil certain functions or uses. These properties, for that matter, refer not only to the characteristics of the medium that is employed but also to the broader contexts of both production and use.

Mitchell distinguishes between two types of representational "constraints" or, put differently, two factors that both the producer and user will have to take into account when trying to apply visuals successfully in a communication and cognition process. First, there is what he calls *"representational commitment,"* by which he means that certain techniques are (more) appropriate for recording certain things and less suited or even totally unsuited for recording others: "different medical-imaging techniques—CT, ultrasound, PET, MRI, and so on—are committed to acquiring different types of data about bony and soft tissue diseases and physiological activities, and so are used for different diagnostic purposes" (Mitchell 1992, 221). Similarly, black-and-white photography may offer the right kind of detail to study naturally occurring phenomena in a social

context and thus may be an ideal tool for anthropologists and sociologists, but in some instances this representational choice will be less than adequate. This will be the case, for example, when documenting trends in fashion, home decoration, or the like, where the use of color embodies essential information, or when a detailed account of processes is required, which can only be achieved by means of a continuous record of moving images. A second requirement that Mitchell puts forward is that a visual representation "must have the correct type of *intentional relationship to its subject matter*" (Mitchell 1992, 221, italics added). Some examples may help illustrate the importance of this requirement: The picture of an escaped convict may help police track down that particular individual, but his facial characteristics cannot be used to identify other individuals with criminal tendencies before they can actually commit a crime. A scan of a pathogenic heart may serve as a diagnostic tool to help one particular patient, but that is not to say that it is the most appropriate representation for use in a general biology textbook. A picture of a young blond girl living in Norway could be used as a visual representative of the Norwegian population, and as such she would be *interchangeable* with thousands of other Norwegian girls. However, if one uses a particular picture of a young blond girl on a missing person poster, it is not necessarily the girl who bears the greatest resemblance to the picture who is being traced, but the actual girl who is represented in the photo, even if she might today no longer resemble that image at all. This implies an indexical, not just an iconic relation!

Mitchell's dual requirement that particular representations should be (1) "fit for the particular uses to which they are put" (representational capability) and (2) be "about the right sort of thing" (intentional positioning) may remind us of the long-established scientific requirements of *representativity* and *validity*, and indeed can serve as an important element of their much-needed visual translation. Both terms underscore once again the paramount importance of distinguishing clearly between the varying functional capabilities of different types of visual representations in science. Moreover, they may help overcome the idea that visual media have intrinsic representational qualities irrespective of their use and production context (e.g., the false but persistent view that photography is always better at describing than drawings, or that paintings are always more expressive than photographs, and that the latter are highly "objective" records).

Yet the same medium types of representation may serve a great many purposes and they may entertain widely divergent relations with the depicted matter. Furthermore, a particular visual representation that was made for a specific purpose may be suitable for other purposes, even for some that were not envisioned at the time of production. However, in most cases one needs to know exactly how the images or visual representations came about and what their broader context of production was before one can assess their validity for those other purposes. The use one can make of a representation is determined, to a considerable extent, by its generative process (choice of visual medium and broader production aspects, choices regarding style, selection and preparation of subject, normative systems) vis-à-vis its intended use. So, insofar as this is possible, a predetermined purpose should guide the production process. Some purposes (e.g., the exploration of a naturally occurring phenomenon) may require an indifferent, detailed account of particularistic data in their specific context, while others (e.g., educational aims) may be served better by highly stylized and synthetic representations highlighting only the essence of a more general phenomenon. So the medium and techniques in part will determine the uses that can be made of a representation, but even representations produced with the same medium or technique may have widely divergent intents and representational positions.

Kinds of Intents and Purposes

The intents and purposes of visual representations in scientific discourses are manifold. For one thing, natural phenomena might be visualized for the purpose of *further analysis:* to make a diagnosis, to compare, to describe, to preserve for future study, to verify, to explore new territory, to generate new data. Representations that serve these primary purposes often will be algorithmic in nature and they may have only an *intermediate* function, since they are primary *data*. Visual representations that have no material referent may serve primarily to *facilitate concept development* or to uncover relationships, evolutions (e.g., through charts of all kinds) and, in general, to make the *abstract more concrete* and thus more accessible for further inquiry. Forms of externalized thinking (conceptual graphs) may be useful both on an intra-personal level (for example, to guide researchers in a dialogue with themselves) and an inter-personal/inter-specialist level (to exchange ideas in an early stage, to invite feedback, or to prompt co-operation from peers).

Visual representations not only serve analytical and intermediate purposes, but they are often also used to *summarize or synthesize* empirical findings or a theoretical line of thought. Thus they may provide an over-

view, display results in their spatial organization or conceptual relations, or clarify the textual or numerical part. More synthesized or purposefully assembled visual representations in science generally serve to facilitate knowledge transfer in a variety of ways and seek to communicate with diverse audiences. They can illustrate, demonstrate, or exemplify features, relations, and processes, or provide mediated experiences in ways that are adapted to the audience (which may vary from highly specialized to lay audiences).

Many visual representations intentionally or inadvertently will embody an implicit or more explicit view on or argument about what is being presented visually, through the many elements and choices that make up the representation. This expressive function of scientific visualizations need not be a problem as long as it is duly acknowledged and, if so required, explained. As intentional forms of communication and through the selection and formal execution of the representations as well as by their thoughtful arrangement in the broader context of an article—a presentation or a multimedia product—visual representations will attempt to exert a certain amount of persuasion. Often, receivers or users of the representation will be invited, seduced or even compelled, in subtle ways, to adopt the views of the sender and to perform the preferred actions (to believe, give approval, appreciate, change opinions, donate money, or support morally). For those reasons, but also for the more acclaimed function of cognitive transfer and education, a visual representation may perform the function of an eye catcher, a means to arouse and maintain attention and interest, or even to entertain the reader/spectator (and thus bring them into the right mood for acceptance). Some aspects of a visual representation in science may even perform no other function than to appeal to the aesthetic feelings of the receivers or just be an expression of the personal aesthetic preferences of the maker. These latter functions, though not readily associated with a scientific discourse, are not necessarily detrimental to the mission of a scientific undertaking, as long as these traits do not interfere with the more fundamental functions of data or cognitive transfer, and on condition that transparency is provided.

While one can never be complete in the listing of possible functions and intents of a scientific visual representation, this brief discussion of functions demonstrates that the idea that scientific visualizations and representations are solely meant to generate and present *objective* data or to facilitate pure cognition should be abandoned. It should be clear that most functions and intents that are found in human communication in general also will be found in scientific representation, though some functions and

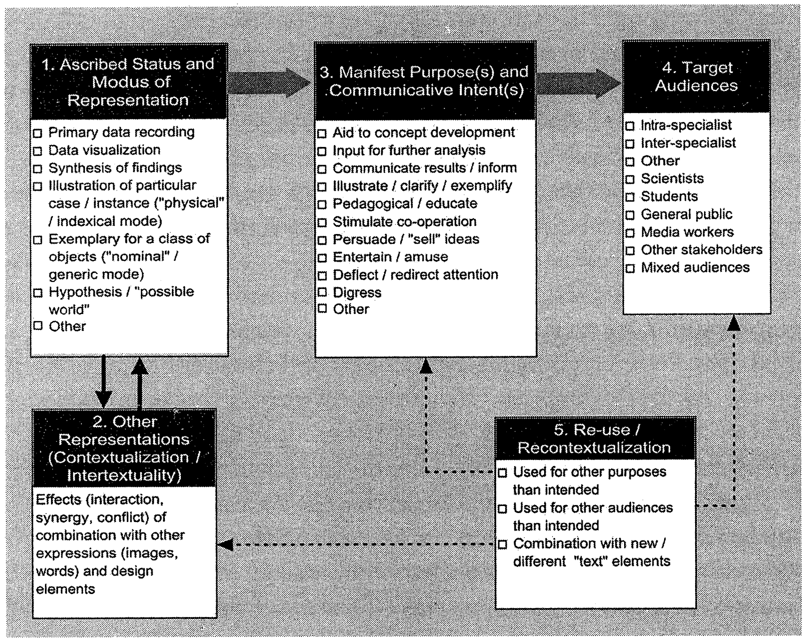

Figure 1.4. Representational status, context, and use: connections between representations, purposes, and audiences.

Chart flow: Visual representations with a particular ontological status (1), in interaction with other representational and presentational elements (2) may be used for different purposes and intents (3) with specific target audiences (4) in mind. Subsequent uses (5) may involve new goals (3) and new *textual* combinations (2) for different audiences (4) and may challenge the ontological status and the representational *fit* of the original presentation (1).

intents obviously will serve a more central role while others will not feature prominently or may be intended to perform an auxiliary function. Moreover, it should be clear that any visual representation used as part of a scientific discourse will serve and combine different functions at the same time, whether intentionally or unintentionally. These purposes may be scientific in a narrow sense, but they may also have to do with intents that lie outside the realm of the acknowledged scientific purposes, such as to serve vested interests of persons and institutions (see, for example, Lynch and Edgerton 1988). Finally, it should be stressed that the different functions that are embodied by aspects of the visual representation may be read or *decoded* in many different ways by different receivers (based on their intents, experience, formal background, etc.) in different contexts and over time. This need not always pose a problem. As scientific work

routinely is characterized by many different skills, viewpoints, and goals spread over as many actors, the vagueness and multi-interpretability and multi-usability of the same representations may at times even play an important role in mitigating possible tensions among these heterogeneous contexts of actors, viewpoints, and functions (specialized and non-specialized audiences: scientists, designers, sponsors, management, etc.) and promote co-operation and mutual understanding. Star and Griesemer (1989) have coined the concept "boundary object" to denote such interfaces between multiple social worlds that serve to facilitate the exchange of skills, knowledge and materials among different social actors (Roth and McGinn 1998, 42). For instance, a map of an area, which is always a highly reductive representation, may be a "boundary object" to the degree that it is accepted and used by multiple parties to serve their needs. It then becomes a communication device across social and disciplinary boundaries.

5. Conclusion: Developing Visual Scientific Literacy

The principle underlying this chapter is that representations and representational practices may be extremely helpful in developing, clarifying, or transmitting scientific knowledge. However, when not produced and used with extreme care and competence, they may create at least as much confusion and misunderstanding. If one considers scientific representations and the ways in which they can foster or thwart our understanding, it is clear that a mere *object approach*, which would devote all attention to the *representation* as a free-standing product of scientific labor, is inadequate. What is needed is a *process approach:* Each visual representation should be linked with its context of production. Moreover, it cannot be understood sensibly outside a particular and dynamic context of use, re-use, and reception. However, given the great many types of referents, representational techniques, purposes, and uses, it seems fair to assume that the vast consequences of this requirement are hardly grasped by the growing number of people who produce and use visual representations on a daily basis.

Scientists should develop a sensitivity for the wide variety of visual representational practices and products and the many ways in which they can be deployed in scientific discourse. Furthermore, a real set of skills is needed in order to be able to *assess* the usability of given representations based on a thorough knowledge of their generic processes, and to be able to *produce* visual representations with the required representational and expressive properties in relation to their purpose(s). Visual representations invariably have a strong communicative function, certainly with regard to the originator (e.g., to guide his or her thinking, or to serve as data for further analysis), but often also toward a variety of specialized and non-specialized audiences. Unconsciously applied and/or unmotivated use of aesthetics and unexplained use of certain conventions are a potential hazard, while well thought out and reflexive use of aesthetics, formal choices, and well-explicated representational codes and conventions may create hitherto not fully exploited opportunities to further scientific knowledge building and communication. Modern technology offers many complex ways of generating images, but few users have a clear understanding of all the steps involved. To counter this emerging "black box syndrome," it is clear that scientists need to keep track of new media technologies to the extent that they offer new ways of looking and (not) knowing.

This complex set of requirements involving specific knowledge attitudes and skills may be understood as a specific kind of visual literacy for scientists. Visual literacy for scientists therefore can be defined as a reflexive attitude (throughout the production process), a specific body of knowledge, and even a certain level of proficiency or skill in assessing and applying specific characteristics (strengths and limitations) of a particular medium, and awareness of cultural practices (codified uses, expectations) and the actual context of use (including the *cultural repertoire* of the intended audience). In other words, a visually literate scholar should be aware of the impact of the social, cultural, and technological aspects involved in the production and handling of representations, as well as the different normative systems that may be at work and how they exert a determining influence on the eventual appearance and the usefulness of representations.

Visual scientific literacy shouldn't just imply establishing a clear division of labor (every person keeping to his or her trade) and then linking together those various types of expertise, as in fact they need to be merged rather than developed and applied according to a separate logic for each specialized aspect. The different normative systems (e.g., scientific, technical, creative, cultural) that are employed consciously or unconsciously need to be combined skillfully with a view to the ultimate purpose of the representation. While expertise obviously cannot be accumulated endlessly in one and the same person, a serious effort should be made at providing a unifying framework whereby each contributor develops a knowledge about and sensitivity for the bigger whole. What they should not do is lock themselves up in their own area of expertise, as hardly any choice that is made along the way is without epistemological consequence.

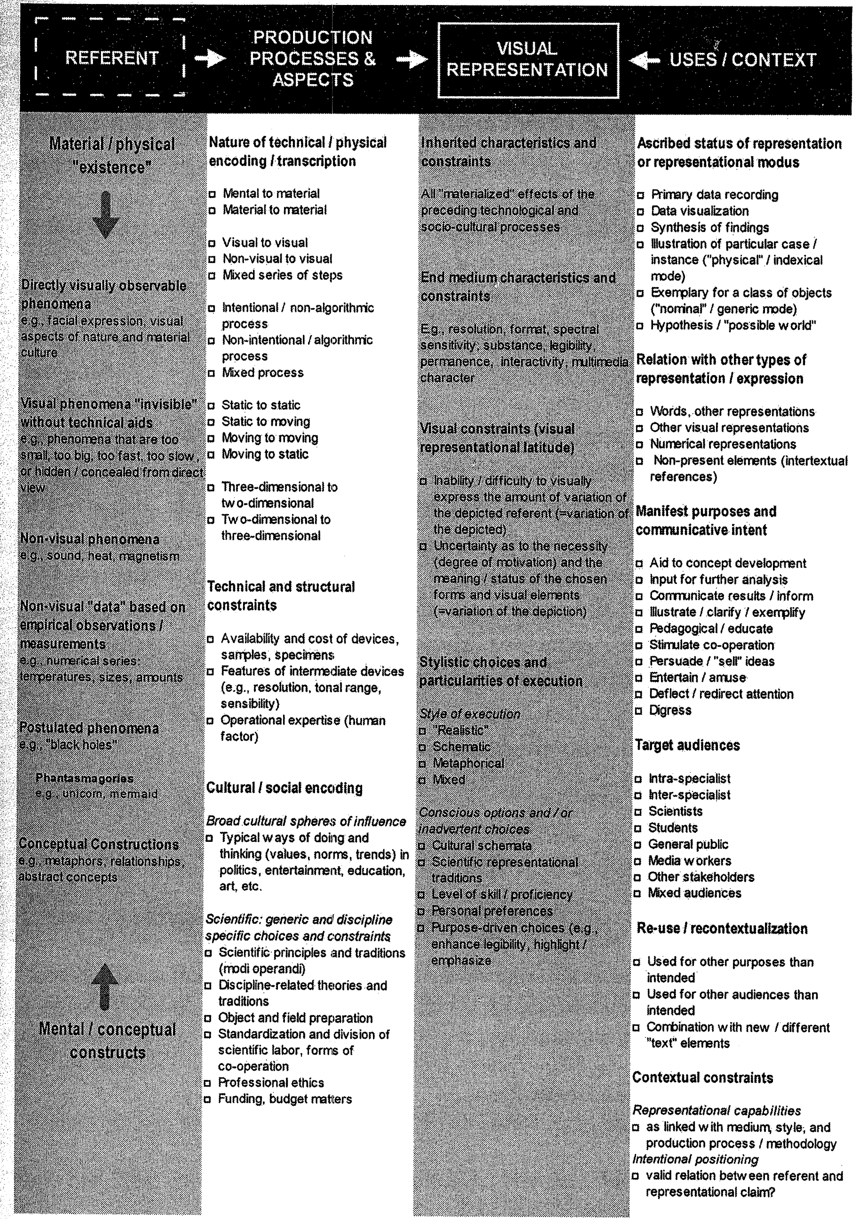

Figure 1.5. A conceptual framework for analyzing and producing visual representations in science.

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Figure 1.5. A conceptual framework for analyzing and producing visual representations in science.

The aspects and issues that have been discussed in this chapter may serve as a theoretical framework for the thoughtful production of visual representations in science or they may be used as a tool to assess critically the appropriateness of different aspects of particular representations. Such a framework may prove useful in examining the complex interdependencies that exist among the nature of the referent, the social, technological, and cultural context of production, the choices with respect to medium and style of representation, and the purposes and uses that need to be achieved. Figure 5 is an attempt to summarize and in a very limited way visualize the elements and arguments of this framework as gradually developed from figures 1 through 4. While these schematic representations may help to map the complex issue of visualization and visual communication in science, to some extent they will remain inadequate for visualizing the complex interrelations among its constituent parts. Nor will they ever be complete and fully self-explanatory in any of their dimensions. Interestingly, while these figures may serve to clarify and promote insight, they inevitably will also obscure and hinder insight to some degree, but this in itself actually illustrates one of the arguments put forward in this chapter. Visual representations always will be used to enlighten and broaden our understanding, while at the same time, they will obscure it. It is the task of visually literate scholars to make sure that the enlightening aspects gradually gain the upper hand.

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