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“Visions visualized? On the evidential status of scientific visualizations”

Nicola Mößner
RWTH Aachen University, Department of Philosophy

1 Introduction

In 2012 the discovery of the so-called *Higgs boson* was announced by scientists working at CERN in Geneva. An important part of this announcement comprised various graphics visualizing—the measurement results within the instrument—the LHC (Large Hadron Collider). The scientists used these images to document the discovery of the subatomic particle, that is they regarded them as evidence for the success of their investigation. But what exactly did these images show? Let us take a closer look at one of them (see Fig. 1).[1]

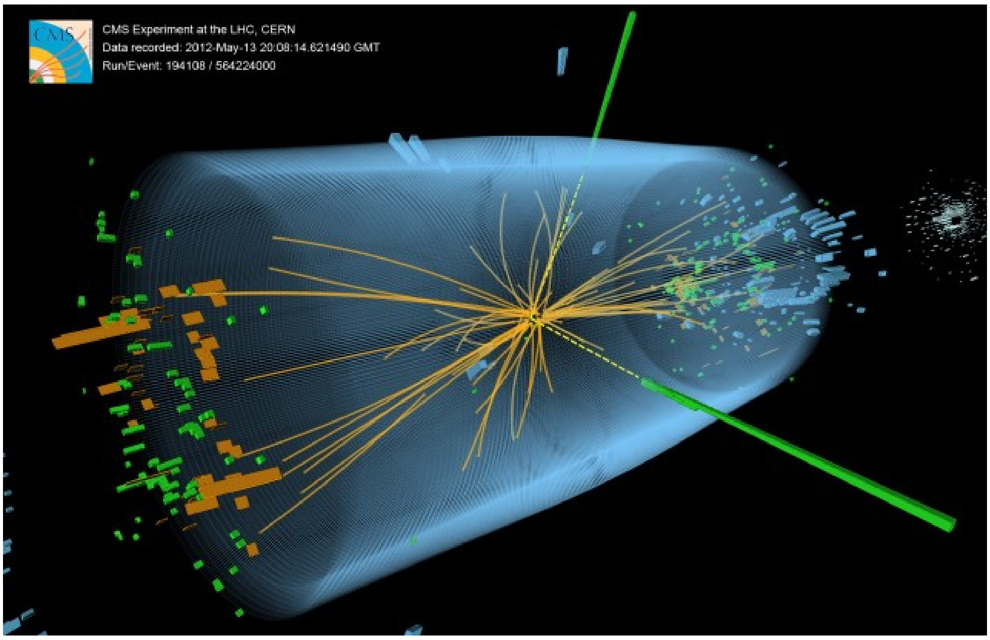

Fig. 1: CMS[2] experiment, (c) CERN (License: CC-BY-SA-4.0), source: http://cds.cern.ch/record/1459463

We see an artificial tube, a lot of orange lines with an apparently common center, and two dashed yellow lines ending in green towers that emerge from the center at a particular angle. What do these colored lines tell us about the Higgs? And if this image can be evidence of its discovery, then what part of the image represents the particle?

The caption to the image tells us: “Event recorded with the CMS detector in 2012 at a proton-proton center of mass energy of 8 TeV. The event shows characteristics expected from the decay of the SM[3] Higgs boson to a pair of photons (dashed yellow lines and green

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[1] This is only one example of the diverse visual representations presented in relation to the discovery of the Higgs boson at CERN. Admittedly, for the scientists involved the diagrams showing the statistical evaluation of the measurement data published in the same official announcement might have had greater significance with regard to their status as evidence of the discovery. Nonetheless, the visualization discussed here shows one of the events that was regarded as relevant in those statistics, i.e. it is part of the statistical basis confirming the detection, and in this sense it was distributed widely amongst experts and laymen.

[2] *CMS* stands for *Compact Muon Solenoid*.

[3] *SM* means *standard model*.

towers)."[4] Consequently, this is not an image of the Higgs boson at all, in the sense of being a direct representation of this particle. On the contrary, what we see is an *indirect measurement with the aid of indicators*. The theory predicts that a particular radiation pattern will be visible if a Higgs particle decays to two photons.[5] Thus, a possible interpretation of the image is that it is exactly this decay caused by a previously present Higgs boson that we can see in the image. However, the measured radiation of the decay makes the hypothesis about the detection of a Higgs only probable not certain. Other explanations for the detected event might still be possible.

This example about the discovery of the Higgs boson takes us directly to the heart of the debate between *scientific realists* and *anti-realists*[6] and their quarrel about *theoretical entities*[7] in science. Visualizations of unobservable entities such as subatomic particles, e.g. the Higgs, rely heavily on instruments and information technology devices to produce these images. Furthermore, these images are not immediately understandable but demand a lot of interpretation and, thus, theoretical background knowledge to grasp what they show. Both aspects—the necessity of instruments and the relevance of theories to access the world of the unobservable—suggest *epistemological* as well as *ontological questions* about the apparently depicted entity and the evidential status of its visualization.

In this paper, we cannot appropriately deal with all of these difficulties. Thus, I will focus my considerations on Adina L. Roskies's thesis that some visualizations of particular measurement devices are 'inferentially more distant' to their object of depiction than others.[8] The aim of this paper is to highlight the point that those concerns, expressed by Roskies, do not have to be regarded as speaking against the evidential status of visualizations in science in general. Let us start with a short introduction to the debate between scientific realists and anti-realists and the place of visualizations.

2 Visual information and the creation of things

There are now a great variety of different theoretical approaches involved in the debate between scientific realists and anti-realists. To obtain a first idea about the basics of this debate, a rough conception might be as follows: The quarrel is about the *status of scientific theories* or—more generally speaking—about the *products* or *outputs of science*—that is, theories, laws, predictions, hypotheses etc.[9] What *do* and what *can* they tell us about the mind-independent world? In this context, scientific realists take a positive stance towards this question in the sense that they believe that our best scientific theories "yield knowledge of aspects of the world."[10] Or, as Richard Boyd puts it: "Scientific realists hold that the characteristic product of successful scientific research is knowledge of largely theory-

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[4] "CMS Higgs Seminar (4 July 2012): images and plots from the CMS Statement", accessed September 15, 2014, http://cds.cern.ch/record/1459463.

[5] Other types of radiation are also possible as a result of the decay. However, contrary to the case of photons, there are more subatomic particles that can be the source of such radiation patterns. Consequently, inferring the decay of a Higgs boson in those instances would be less reliable than in the case of two photons.

[6] Helpful introductions to this topic are presented by Anjan Chakravartty, "Scientific Realism," in *The Stanford Encyclopedia of Philosophy*, ed. Edward N. Zalta (2013), accessed September 15, 2014, http://plato.stanford.edu/archives/sum2013/entries/scientific-realism/; James Ladyman, *Understanding Philosophy of Science* (London: Routledge, 2003); Christian Suhm, *Wissenschaftlicher Realismus – eine Studie zur Realismus-Antirealismus-Debatte in der neueren Wissenschaftstheorie* (Frankfurt/Main: Ontos, 2005).

[7] Concerning the topic of theoretical entities in scientific realism see Christian Suhm, "Theoretische Entitäten und ihre realistische Deutung – Realismus einer Strategie zur Verteidigung des wissenschaftlichen Realismus, " in Christian Suhm and Christoph Halbig, eds., Was ist wirklich? Neuere Beiträge zu Realismusdebatten in der Philosophie (Berlin: De Gruyter, 2004).

[8] See Adina L. Roskies, "Neuroimaging and Inferential Distance," *Neuroethics* 1 (2008): 19-30.

[9] Others would say that the debate is about the possibility of progress in science, see Chakravartty (2013), sect. 1.1. (as in n. 6).

[10] Chakravartty (2013), sect. 1.1. (as in n. 6).

independent phenomena and that such knowledge is possible (indeed actual) even in those cases in which the relevant phenomena are not, in any non-question-begging sense, observable."[11]

This last quotation from Boyd makes clear that there are many more aspects involved and under dispute than our first approximation to the topic might suggest. In accordance with this, Anjan Chakravartty points out that there are *three* different levels (or questions) of inquiry involved, an *ontological*, an *epistemological*, and a *semantic* one. "Ontologically, scientific realism is committed to the existence of a mind-independent world or reality. A realist semantics implies that theoretical claims about this reality have truth values, and should be construed literally, whether true or false. ... Finally, the epistemological commitment is to the idea that these theoretical claims give us knowledge of the world."[12] Moreover, these three levels can also be combined in different ways. One can, for example, be a realist with regard to the ontological level, but at the same time not with respect to the epistemological, etc.

Anti-realists, on the other hand, deny the positive attitude that scientific realists take towards the products of science or towards the status and capabilities of scientific theories. In accordance with the above differentiation, *anti-realistic approaches* are as diverse as the different combinations of these three levels of inquiry.[13] However, what is more important for our current concern about scientific visualizations is that the debate between scientific realists and anti-realists sparks off especially with regard to the *unobservable* part of our world. Again Chakravartty offers a useful categorization. "Unobservables, then, are things one cannot perceive with one's unaided senses, and this category divides into two subcategories. Some unobservables are nonetheless detectable through the use of instruments with which one hopes to 'extend' one's senses, and others are simply undetectable."[14]

An instance of the detectable category of unobservables is the Higgs boson mentioned in our initial example. Philosophers of science call instances like this "theoretical entities"[15], that is, entities that are predicted by scientific theories, but are not observable without the use of instruments. The Higgs boson, for instance, is part of the "standard model" of physics[16] and plays a constitutive role here as it is said to provide masses for all other subatomic particles. Furthermore, the Higgs can only be detected in a particle collider such as the LHC—or rather its traces as the Higgs is not a stable particle, that is, it quickly decays into other subatomic particles.[17] Consequently, what we actually observe with the aid of visualizations of the measurement process are these decays of the Higgs boson which, again, are predicted by the correlated theory.

Hence, the question that we will be concerned with in the following is *what evidential status such visualizations might have with regard to the unobservable*. On the one hand, they apparently give us access to the domain of theoretical entities, in the sense of seemingly granting the existence of something that we can inquire into even further. On the other hand, these visualizations rely heavily on theoretical assumptions—for example, where to look for

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[11] Richard Boyd, "What Realism Implies and What It Does Not," *dialectica* 43 (1989): 6, 5-29.

[12] Anjan Chakravartty, *A Metaphysics for Scientific Realism* (Cambridge: Cambridge Univ. Press, 2007), 9. For more details see also Chakravartty (2013), sect. 1. (as in n. 6); Suhm (2005), ch. 2.2 (as in n. 6).

[13] Chakravartty offers a helpful table that categorizes the different positions with regard to their stances concerning the above-mentioned three levels of inquiry see Chakravartty (2007), 10 (as in n. 12).

[14] Chakravartty (2007), 4 (as in n. 12).

[15] See Holger Andreas. "Theoretical Terms in Science," in *The Stanford Encyclopedia of Philosophy*, ed. E. N. Zalta (2013), accessed September 15, 2014 http://plato.stanford.edu/archives/sum2013/entries/theoretical-terms-science/.

[16] For more information about the standard model see Glenn Elert, *The Physics Hypertextbook*, (2014), accessed September 15, 2014, http://physics.info/.

[17] See "Observation of a New Particle with a Mass of 125 GeV", accessed September 15, 2014, http://cms.web.cern.ch/news/observation-new-particle-mass-125-gev.

the entity to be detected and how to measure it, and how to make it visible showing which properties, etc. Consequently, one might feel tempted to highlight the artificial character of those visualizations and, thus, to call into question their apparently evidential status.

The problem that is addressed here is known as the *theory-ladenness of observation*[18] in philosophy of science. Martin Carrier[19] and Peter Kosso[20] make us aware of the fact that this is also a multifaceted problem. Theoretical assumptions come in on the level of *observations*; theories tell us where to look for our object of research. On the level of *observation statements*, theories yield the vocabulary to describe our findings. And on the level of *measurement processes*, theories tell us how to evaluate and interpret our data. Analyzing all of these dimensions would be well beyond the scope of this paper, thus we will take a more detailed look at only one of these aspects, namely the problem of interpretation correlated with visualizations of the above-mentioned kind.

3 **Problems of interpretation**

Evaluating visualizations as measurement results can be done in two different contexts, namely the *explanatory* and the *exploratory* context of science.[21] Whereas the former is correlated with the publication and distribution of scientific results and hypotheses among the community and also the broader public, the latter is about the activity of research itself. In the following we will be concerned with this latter context. Here visualizations are often regarded as a kind of *surrogate for the object under investigation*, as direct observations might not be possible, especially not with respect to theoretical entities such as the Higgs boson.

Although such substitutions in the process of research seem to be common practice in science, the evidential status of visualizations can be called into question due to the problem of theory-ladenness mentioned above. Laura Perini identifies the difficulty when she states that “[t]he problem with MPIs [mechanically produced images, NM] stems from the fact that they could be interpreted in a variety of ways.”[22] This *relevance of interpretation* and the apparent possibility of fulfilling this requirement in different ways might then raise anti-realistic worries with respect to the evidential status of visualizations.

To come to grips with the problem and also to suggest a way out, we will take a closer look at Adina L. Roskies’ analysis of fMR images (functional magnetic resonance images).[23] Such images are widely used in neuroscience to investigate human brain activities and, presumably, correlated mental phenomena. In this sense, they visualize an otherwise unobservable entity just as the CMS image does in our example above.

In this context, Roskies points out that many laymen regard fMR images in analogy to photographs. And, because of this reasoning, they also transfer assumptions about the evidential status of the latter to the former mode of representation. However, Roskies makes us aware of the fact that this analogical reasoning is not valid as there are significant differences between the two modes of visual representation. Most of all, they differ with respect to their “inferential distance”. Roskies introduces this technical term to explain the

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[18] I analyzed this topic in relation to scientific visualizations in more detail in Nicola Mößner. “Photographic Evidence and the Problem of Theory-Ladenness,” *Journal for General Philosophy of Science* 44 (2013): 111-125.

[19] See Martin Carrier, *The Completeness of Scientific Theories—On the Derivation of Empirical Indicators within a Theoretical Framework: the Case of Physical Geometry* (Dordrecht: Kluwer Academic Publishers, 1994).

[20] See Peter Kosso, *Reading the Book of Nature*, reprinted ed. (Cambridge: Cambridge Univ. Press, 1993).

[21] See Felice Frankel and Angela H. DePace, *Visual Strategies—A Practical Guide to Graphics for Scientists and Engineers* (New Haven and London: Yale University Press, 2012), 13. I argued in more detail for the relevance of keeping these two contexts distinct when discussing the evidential status of scientific visualizations in Nicola Mößner, “Visual Data—Reasons to Be Relied on?” in Nicola Mößner and Alfred Nordmann, eds., Reasoning in Measurement (Routledge, forthcoming).

[22] Laura Perini, “Image Interpretation: Bridging the Gap from Mechanically Produced Image to Representation,” *International Studies in the Philosophy of Science* 26, no. 2 (2012): 166, 153-170.

[23] See Roskies (2008) (as in n. 8); Adina L. Roskies, “Are Neuroimages Like Photographs of the Brain?,” *Philosophy of Science* 74 (2007): 860-872.

amount of interpretation that is relevant to understand what a visualization shows.[24] Labelled in this latter way the correlated problem to account for the epistemic status of different measurement data or visualizations already partly[25] was addressed by Kosso in the 1980s.[26] He states that the "[a]mount of interpretation is a measure of epistemic closeness between the apparatus- and object-states."[27] Interpreting Kosso's claims, Christian Suhm describes this aspect as referring to the epistemic distance between observer and the object under investigation.[28] He states that Kosso's suggestion can be regarded as a *quantitative epistemic benchmark*, which points out how many theoretical assumptions have to be involved for a justified inference from a causal effect in the measurement device (or the observer) to the ascription of a particular state or property on the part of the object under investigation.[29] It is exactly this kind of quantitative epistemic benchmark that Roskies addresses by her suggestion of "inferential distance" as a criterion to explain the difference between the evidential status of a photograph in comparison to that of a brain scan.

Moreover, Roskies's analysis helps us to make explicit where exactly interpretations are needed in the epistemic process of understanding visualizations. She identifies two different projects of interpretation that are of relevance, which she calls the "causal stream" and the "functional stream".[30]

Interpretations with regard to the *causal stream* are related to the relevant background theory of the instrument used. To interpret the resulting images correctly we have to know what the detecting device is sensitive to. Roskies highlights the fact that, contrary to photography, most people and especially laymen do not "understand the causal and counterfactual relationships between the [fMR, NM] images and the data they represent."[31] Of course, fMR images are causally dependent on a particular object. However, in two ways this is different to the case of photography. On the one hand, also professional users of fMR images often lack an understanding of the technology involved, that is, they do not know, for example, when the measurement failed and only artefacts were produced. Thus, what the observer lacks in the case of brain scans is a *robust understanding of the causal imaging process*.[32]

On the other hand, and this brings us to the second, the *functional project* of interpreting fMR images, Roskies claims that another difficulty consists in the fact that (professional) observers also lack a clear understanding of "the connection(s) between task and neural activity and the MR signal".[33] This is related to the experimental set-up where the data are collected and, consequently, to the neuroscientific theory that is tested by the

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[24] See Roskies (2008), 20f. (as in n. 8).

[25] Kosso does not discuss the difference between photography and fMRI. He is concerned with the topic of measurement results more broadly, that is, he is not talking about visual data in particular, but about observational data in general.

[26] See Peter Kosso. "Dimensions of Observability," *The British Journal for the Philosophy of Science* 39, no. 4 (1988): 449-467.

[27] Kosso (1988), 456 (as in n. 26).

[28] See Suhm (2004), 166 (as in n. 7).

[29] See Suhm (2004), 166 (as in n. 7).

[30] Roskies (2008), 23 (as in n. 8).

[31] Roskies (2007), 871 (as in n. 23).

[32] It might be objected that only seldom do the users of technological devices really *understand* their functional principles and that Roskies, therefore, only points out a commonplace. Normally, the *division of epistemic labor* relieves the burden of proving the reliability of the technology involved. However, I think that Roskies wants to make a broader claim here, in the sense of stating that the *expert users* in the case of fMR images do not understand the relevant basics of their technology, that is, they are *unable to use* the technology involved correctly—in the sense of using the correlated images as reliable diagnostic tools. In such cases, pointing to the division of epistemic labor would not be enough to justify their potentially deficient handling of the measurement device and inadequate interpretation of the images that it produces.

[33] Roskies (2007), 865 (as in n. 23).

experiment. Three different components are involved in such a measurement process. There is the *stimulus*, so to speak, that is, the task which the test person has to perform during the scanning process—for example, looking at pictures showing different social situations and thereby provoking different emotional responses. Secondly, there are the properties of the brain which are measured in the scanner. But how exactly is the stimulus correlated with the brain activity? Furthermore, how are brain activities and the *fMR signal* related to each other? And, thirdly, we have to clarify how the brain activity and the patient's *mental life* are connected. Explaining what brain scans show implies being able to identify different patterns and inferring information from them, that is, being able to explain what these patterns might tell us about brain activities and how they might be correlated with mental phenomena such as remembering. Here, neuroscientific theories come in, that is, theoretical hypotheses connect all of these parts.

To put it more broadly then, the first domain of interpretation of visualizations concerns the question of how the instrument of an experimental or observational set-up (causally) works. The second domain is about the question of how the measured datum, that is, the visual representation, supports the tested theory. In this sense, Roskies's analysis can be used to shed some light on the evidential status of visualizations in science more generally. In the following, we will take a closer look at both suggested domains of interpretation. On the one hand, we will ask where exactly skeptical assumptions about the evidential status of scientific visualizations might come in. On the other hand, we will discuss some possible strategies to deal with the interpretative difficulties that will allow us to stick to the stance of scientific realism. Let us start with the functional stream first.

3.1 The *functional stream*: interpretations to bridge the gap between theory and datum

Obviously, regarding visualizations as surrogates for research objects only makes sense if scientists are somehow convinced that the former can yield knowledge about the latter, that is, that the image can tell them something *about* the relevant aspects of the object depicted. This also suggests that, at least sometimes, scientists take these images as being *visual representations* of their object of research. Chakravartty puts this "about-ness" in the following way, "... successful representation contains information regarding the thing it represents."[34] However, our initial example about the Higgs boson highlights the fact that in quite a few instances measurements, and thus visual data, are only indirectly related to the object of research. We do not see the Higgs, but rather its decay into two photons depicted on the corresponding image. In what sense can we thus state that this image is about the particle that scientists at CERN are searching for?

If we want to stick to the concept of representation in this context, we have to qualify the proposed *aboutness* of visualizations in such a way that instances referring to indirect measurement processes can be convincingly accommodated.[35] Accordingly, Chakravartty refines his initial claim that a representation of x contains information about the represented object x in the following way, "sometimes this information is rather minimal: in the limit, it may be exhausted by the fact that the subject of representation exists."[36] With regard to our example this means that—by using theoretical background assumptions—we can interpret the visualization in question as *evidence* of the apparent existence of the Higgs boson. However, as Kosso points out, there is still a difference between *observation* and *evidence*, namely "the necessary role of inference in the latter [case NM]. ... In the best circumstances, this inference is supported by a good understanding of the link between what is seen and the interesting thing that is not seen, between effect and cause. ... This understanding is

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[34] Chakravartty (2007), 184. (as in n. 12).

[35] Mario Bunge calls such instances "indicators" which he defines as " an observable counterpart of the unperceivable item." Mario Bunge. "Reading Measuring Instruments," *Spontaneous Generations: A Journal for the History and Philosophy of Science* 4, no. 1 (2010): 86, 85-93.

[36] Chakravartty (2007), 184 (as in n. 12).

theoretical in this sense of being not amenable to a direct observational check. That does not make it bad or suspect, but it does point out that evidence is *a bit riskier* than observation itself."[37] This makes plain *why* the evidential status of scientific visualizations might be called into question. Obviously, there are quite a few inferential steps involved to claiming the existence of the Higgs boson by analyzing visual data apparently showing the traces of two photons. Supporting our claim in this way seems to be "riskier" than supporting a claim by direct observational data. The likelihood of errors or defective reasoning might be higher in the former than in the latter case.

Consequently, two aspects seem to be of importance here. The first one is commonly associated with the use of measurement devices in science in general. They have to be *causally related to the entity* under investigation. However, information about the causal connection will only tell the scientist *that* something has been detected by her instrument, but not *what*. Thus, to be more precise about the referential—and, consequently, the evidential status of the visual representation, the scientist is in need of further information.

In this context, Laura Perini suggests that, in addition to the mentioned causal connection, we need rules "that are at least partly conventional" to interpret scientific visualizations correctly.[38] She thereby refers to Nelson Goodman who thinks that a representational relation solely depends on conventions, that is, anything can be used to represent anything else by mere decision. Contrary to Goodman, however, Perini thinks that this conventional aspect can be reduced by pointing out the "selective sensitivity" of the measurement device or instrument[39] which "provides a non-arbitrary relation between the visible form of the data image and its representational content, because the selectivity of the imaging process determines the type of information the imaging technique can embody in an image and how that information is embodied in the display."[40]

I argued elsewhere for the thesis that Perini's interpretative rules should be understood as *mapping functions* that define a *kind of resemblance* between visual datum and the object under investigation.[41] In the case of the Higgs boson, for example, a particular visible radiation pattern is taken as evidence of the previously decaying particle. Roughly speaking, the corresponding mapping function defines what exactly such a pattern looks like in order to be considered as a suitable candidate for detection.

A lot of critics have indeed argued against the relevance of resemblance with regard to depiction.[42] Nonetheless, in the exploratory context of science, regarding visualizations as surrogates for research objects also implies that the former is somehow *about* the latter and thus can yield relevant information about the latter. In this sense, visual datum and object share some relevant properties. In the above example of an indirect measurement, image and particle share the indicator, i.e. the radiation pattern, as a common feature and thus resemble one another in this respect.

Such a mapping function then tells the scientist how to read off her data correctly. Moreover, this function is not an arbitrary choice in the scientific context. A great many of them are of a law-like conception. Thus, questioning the connections between visual datum and research object would also mean questioning the validity of these laws which are normally embedded within the wider context of a theoretical network.

There is, however, a second way to question the evidential status of visualizations, also related to the difficulty of interpretation. A mapping function can tell the scientist how to interpret her visual datum correctly with regard to the theory at hand. However, this

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[37] Peter Kosso. "And yet It Moves: The Observability of the Rotation of the Earth," *Foundations of Science* 15, no. 3 (2010): 217f., 213-225, my italics.

[38] Perini (2012), 163 (as in n. 22).

[39] Perini (2012), 164 (as in n. 22).

[40] Perini (2012), 166 (as in n. 22).

[41] See Mößner (as in n. 21).

[42] See e.g. Oliver R. Scholz. *Bild, Darstellung, Zeichen – philosophische Theorien bildlicher Darstellung*, 3rd ed. (Frankfurt/Main: Klostermann, 2009), ch. 2.

presupposes the reliability of the causal connection between instrument and object. Let us thus come to Roskies's second domain of interpretation with regard to scientific visualizations.

3.2 The *causal stream*: interpretations to account for a reliable causal connection

The second domain where interpretations are relevant to account for the evidential status of scientific visualizations is concerned with the *reliability of the causal connection* between entity and measurement device. To put it briefly, the difficulty is that the scientist not only has to understand how datum and theory are related, but also how her instrument works.

Such a causal connection supports the following counterfactual reasoning: *If the entity under investigation had shown different characteristics, the measurement results would have been different, too*. Thus, in order to regard a visualization as a surrogate for the measured entity, we have to presuppose that it has been produced by a *causal connection* between the object and a *reliable* instrument. However, both aspects—the causal connection and the instrument's reliability—might be called into question. In this context, Roskies claims that not only laymen in general but also professional neuroscientists often lack the relevant understanding of the causal processes with regard to fMR images.[43] However, Roskies not only explains a particular difficulty of interpreting and understanding scientific visualizations, she also—unbeknownst to her—points out a solution to the problem that is also compatible with scientific realism.

Comparing fMR images with photographs, Roskies states that people have no difficulty in comprehending how photographs are produced[44] due to "our familiarity with photography and with the use of photographic images in science."[45] However, as Kelley E. Wilder rightly shows in her elaborate analysis of photography in science, this familiarity is the result of a long-term process.[46] When photography was firstly introduced in the scientific context, it was confronted with the same sort of difficulties that Roskies highlights in the case of brain scans. Its evidential status was far from being clear. Nonetheless, as Roskies's thesis suggests, scientists were able to overcome this difficulty so that nowadays the technology of photography can be called a *familiar* one. Wilder explains this development by highlighting the fact that experiments making use of photography in science were constantly accompanied by experiments to find out more about the photographic process,[47] most of all about the characteristics and particularities of emulsions used for the photographic plates.[48] Consequently, Wilder shows that it took quite a while before the photographic method became a reliable detective device to record and measure certain processes and entities and it took no less time for scientists to understand this method and to use it correctly and successfully.

Thus, it is only today that we are used to this technology—or "family of technologies" as Patrick Maynard sophisticatedly describes the nature of photography —and take its mechanism of picture production as familiar.[49] Wilder's analysis nonetheless shows that there are ways to establish the reliability of a causal connection between instrument and object. Moreover, now that the initial process of understanding the instrument is completed with regard to photography, findings of these experiments can be used to *calibrate* the instrument

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[43] See Roskies (2007), 871 (as in n. 23).

[44] Most likely, she refers to the analogous mode of picture production here; as it can be argued that few people really understand how pictures are produced by digital cameras.

[45] Roskies (2008), 21 (as in n. 8). On the use of photography as a measurement device see also Patrick Maynard, "Photo Mensura," in Nicola Mößner and Alfred Nordmann eds., *Reasoning in Measurement*, (Routledge, forthcoming).

[46] See Kelley E. Wilder. *Photography and Science* (London: Reaktion Books, 2009).

[47] See Wilder (2009), ch. 2 (as in n. 46).

[48] See Wilder (2009), 52 (as in n. 46).

[49] See Patrick Maynard. *The Engine of Visualization: Thinking Through Photography* (Ithaca, NY: Cornell Univ. Press, 2000), 3.

—that is, to ensure its reliability. Thus, in pointing to this development with regard to the technology of photography, Roskies has also suggested a solution to the problem of interpretation in this realm. Once the relevant causal connection is sufficiently understood, the calibration of the instrument will guarantee the relevant relation. Furthermore, this also shows that the interpretation of images produced by technological devices can become common practice—not only among scientific experts but also among laypeople.

Finally, if a reliable causal connection is available as in the case of photography, the transmission of information that was required with respect to using an image as the surrogate for its object is possible. In this sense, Kosso drives home the point for scientific realism: "a causal account [,] has the existential claim built in in the sense that if you accept the fact that there is information about x which comes from x, then you also get the fact of the existence of the source of information."[50] And as long as the theory of building and understanding the instrument does not converge with the theory to be tested by the data yielded by this device, no anti-realistic worries will destroy this positive result.[51]

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[50] Kosso (1988), 464 (as in n. 26).

[51] This is Kosso's fourth dimension of observability, which he calls "independence of interpretation". Kosso (1988), 456f., 463ff. (as in n. 26).