A Journal for the History and Philosophy of Science
Spontaneous Generations

How Much Work Do Scientific Images Do?

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Source: *Spontaneous Generations: A Journal for the History and Philosophy of Science*, Vol. 6, No. 1 (2012) 115-130.

Published by: The University of Toronto
DOI: 10.4245/sponge.v6i1.17154

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Published online at jps.library.utoronto.ca/index.php/SpontaneousGenerations
ISSN 1913 0465

How Much Work Do Scientific Images Do?*,†

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In this paper, I defend the view that there are many scientific images that have a serious epistemic role in science but this role is not adequately accounted for by the going view of representation and its attendant theoretical commitments. The relevant view of representation is Laura Perini's account of representation for scientific images. I draw on Adina Roskies' work on scientific images as well as work on models in science to support my conclusion.

I. Introduction

As I surveyed my desk at the end of last semester, I saw piles of papers, the result of a semester of not tidying up. Among the notes-to-self and copies of memos to various administrators are pictures, mostly ones I have drawn. One is a picture of the University of Utah's budget process as it relates to my department; another is a picture of evolutionary change presented as change in gene frequency; another is a picture attempting to express the correspondence theory of truth; and my favorite is a visual joke of Spike Milligan whose caption says "It's the little things that count" and the picture is of little things adding numbers. I use pictures to think, to teach, and to communicate ideas. I sometimes take this reliance on pictures to point to cognitive limitations. Perhaps if I were more adept at mathematics, I would be able to present all of these ideas more precisely and with more force. (I doubt mathematics would help making jokes funnier.) Maybe the reliance on pictures is symptomatic of a shared cognitive limitation we humans have or maybe we should cast this

* Acknowledgements: I thank the School of Philosophy at Australian National University for hosting me while I finished up this paper. Thanks also to Kim Sterelny, Michael Weisberg and other audience members at my talk on scientific images at the Australian National University for their helpful comments.

† Received 6 August 2012.

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reliance in a more positive light and think of it as part of the standard machinery for much human understanding. If you look through a random selection of current editions of science journals on the web, you will find thousands of pictures used in many and varied ways. Some could be dismissed as decorative or unnecessary but most, I argue, are indispensable to the relevant scientific work. Here I focus in on a few of the many uses pictures (images) are put to in science. My aim is to push the discussion of images in science in one of the directions that discussions of models in science have gone: away from a unified, representation-based account of how images work in science or do their epistemic work.

Here is how I will proceed. First, I will fill out the claim about the prevalence of images. As we will see, the claim is usually presented along with the claim that philosophers ignore images in science or do not take them seriously. What taking images seriously amounts to is rejecting the once-prevalent view that they are mere decorations and presenting and defending an epistemic role for them in science. Next I will say a little about my way into the discussion about images, which was through my interest in models and modeling in science. In a recent paper I appear to be making the rash claim that scientific images do not represent, which on its face sounds plain wrong (Downes 2009). Here I will give a bit of context to that claim and hopefully defend it for one subset of scientific images and one account of representation (a much weaker position). I go on to present Laura Perini's account of representation for scientific images. Next I present a different approach to specific scientific images found in Adina Roskies' work. Framing Roskies' approach as a response to Perini, we arrive at the preliminary conclusion that one theory of representation for images fails to apply in some cases. I add some further worries about Perini's approach which support a more general conclusion: there are many scientific images that have a serious epistemic role in science but this role is not adequately accounted for by one prominent view of representation and its attendant theoretical commitments.

II. Ubiquity of images in science

In the 1990s more or less everyone writing about scientific images in science studies took it upon themselves to make the case that images are ubiquitous in science before they launched into the real work they were up to. Several people support this ubiquity claim about images with a somewhat quantified approach. For example, Nancy Anderson and Michael Dietrich (2012, 2) quote Robert Blystone's 1989 work making this point: "In the forty years following the end of World War II the average number of pages in biology textbooks almost doubled, the number of photographs tripled, and the pages that had no illustration at all dwindled to only 22 percent." As Michael Ruse (1996) notes, the trend that Blystone identified continued, culminating in a more or less one-to-one ratio of illustrations to page count. Ruse points to Darnell et al.'s massive *Molecular Cell Biology* textbook from 1990, which has 1,105 pages and 1,050 illustrations.

The trend has continued: science journals, textbooks, and trade-books have a vast number of different types of images that play distinct roles. The images scientists use range from photographs taken in good light of medium sized live organisms—such as those used to illustrate typical features of birds or butterflies—to highly abstract and schematic diagrams—such as biologists' diagrams of adaptive landscapes. An image can often be used as data or evidence, for example, micrographs of various kinds; and just as often (I will argue) images are the way of presenting a model or a theoretical construct, for example, the iconic diagram of the Bohr model of the atom. Images can be used to represent ideal situations, to outline parts of an ideal structure or part of a postulated process or mechanism, to render depth in two dimensions, to illustrate mathematical expressions, and so on. There is no one use of images.

So images are widespread in science, "So what?" The next stage of this project is to answer that question. The claim being rejected is that images are decorations, mere sideshows to real scientific work. A weaker version of this claim—images are pedagogical (merely pedagogical) and do not do any epistemic work in real science—is also rejected. Rather, images are used to help the uninitiated learn about that real science. Ruse (1996), Anderson and Dietrich (2012), Perini (2005a; 2005b), Roskies (2007; 2008; 2012), and many others take these claims on and understand that demonstrating the mere presence of images does not make the case for an important epistemic role for them in the sciences. Many cite Stephen J. Gould (1991, 171) in this context: "Scientific images are not frills or summaries; they are foci for modes of thought." Gould here clearly denies the mere decoration thesis and, implicitly, the mere pedagogy one too and gestures in the direction of an epistemic role for images. Ruse develops Gould's point and directs it at philosophers. He says that philosophers "did not talk about biological illustration because they did not judge it to be part of 'real science.' This enterprise produces statements or propositions, ideally embedded in a formal system" (Ruse 1996, 304). He saddles many well-known logical empiricist philosophers of science with this view and, for good measure, blames Plato for it and reminds us of Pierre Duhem's position that it was only human weakness that resulted in visual aids being required in the service of science.

Now that the case has been made that images are an indispensable part of science, the next task is to spell out the epistemic work that scientific images do. As Ruse indicates, at one end of the spectrum there are those who believe that images do no real epistemic work and, at the other end, there are those who believe that if images do any epistemic work, there must be one unifying account of how they do so. I hold that scientific images function in a number of ways, doing different kinds of epistemic work and, sometimes, none at all. Before I turn to one account of the epistemic role of scientific images in some detail, I will first say a little about scientific models, as I will draw on work on models and apply it to scientific images.

III. Models

Much work in philosophy of science on models emphasizes their representational role. Here is how Paul Teller (2001, 397) puts this point: "I take the stand that, in principle, anything can be a model, and that what makes a thing a model is the fact that it is regarded or used as a representation of something by the model users. Thus in saying what a model is the weight is shifted to the problem of understanding the nature of representation." In this account, models stand in some representational relation to a world system or the observable aspects of that system. This view comes along with a system of epistemic appraisal centered around the fit of the model with the world or the observed world. Rather than claiming that models are true or false, most have claimed that models are isomorphic with the system they represent or similar to that system in various respects and degrees.

In developing his influential version of this view, Ron Giere (1988; 1996; 1999a; 1999b; 2004) reminds us that any definition of models that philosophers of science give should be constrained by what scientists take models to be. An important part of the philosopher of science's job, according to Giere, is to characterize actual scientific practice. His account of a model keeps this constraint on philosophy of science front and center: for him models are the idealized systems discussed in scientific textbooks (Giere 1988, 78-80). Such idealized systems can satisfy specific sets of equations, such as a simple harmonic oscillator in mechanics, but may also be idealized systems such as models of sea floor spreading in geology, which do not satisfy specific sets of equations and are not even presented via equations. Continuing the emphasis on representation, Giere provides an account of scientific theories, which are collections or families of models that represent the world (see Figure 1). Giere takes the relevant representation relation to be one of similarity. The representationalist view of scientific models is attractive. Our examination of scientific practice tells us that scientists trade in models and if the epistemic value of these objects can be cashed out in terms of some type of representation relation, for example, similarity, then we have the makings of a nice unified account of science. On this account science, or at least model-based science, to use Peter Godfrey-Smith's (2006) terminology, is successful to the extent that scientists produce models of the world that are similar to their objects, or observable aspects of those objects, in relevant respects and degrees.

What is the relevance of bringing up models in a paper about scientific images? First, we need to look no further than Giere (1996, 272), who says

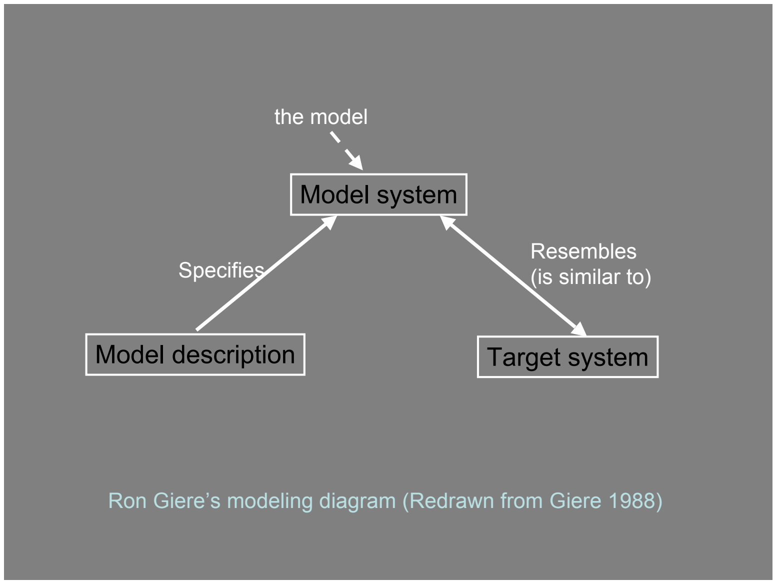

Figure 1. Stephen M. Downes redrawn from Giere, 1988. Sketch of Giere's view.

"[my] model-based understanding of scientific theories makes it possible to treat things like diagrams [...] on a par with the more abstract theoretical models that, on this account, form the core of any scientific theory," For Giere, models and images share a representation relation with their objects, both being similar to real systems in specific respects and degrees. Giere regularly emphasizes that truth is a relation apt for sentences but not for models or images. As we shall see below, Perini (2005a, 2005b) disagrees with Giere about the appropriateness of invoking truth for images. The second relevant connection between work on models and images comes from a recent paper of mine (Downes 2009) in which I criticize Giere and others' similarity-based accounts of representation for both models and pictures in the same way. I go on to claim, but not express or argue for in much detail, that both models and images play important roles in science that cannot all be accounted for by appealing to any of the going notions of representation. This implies that I hold the view that scientific images do not represent. I aim to explain this thesis of that paper by defending a much weaker version of it here. But first, I turn to Perini's view of images.

IV. Perini on how scientific images represent.

Perini has made helpful inroads into the problem of how scientific images do their epistemic work. She presents and defends an account derived from Nelson Goodman's (1976) symbolic approach to understanding pictures, which allows us to understand them as either true or false. Pictures for Perini include "photographs, perspective drawings, courtroom sketches, etc." (Perini 2005a, 273). The key for her is to establish that pictures themselves have truth conditions, rather than the various sentences that guide our use and understanding of the pictures. As she puts it, "Demonstrating that scientific figures can bear truth will require showing that their symbol systems support the capacity to bear truth, independent of mediation by other representations to assign meanings to individual members of the visual symbol system (that is, without using linguistic representations as the underlying system)" (Perini 2005a, 274-75). She argues that her approach can be applied fairly straightforwardly to scientific diagrams that can be broken down into atomic parts, whose relations to one another can be expressed linguistically. However, there are worries that images such as electron micrographs may not be susceptible to her analysis. Even in this case and similarly worrisome cases she claims that an "informal" description of the relation between the image and its object can be given. From this reasoning, she concludes that "an electron micrograph is true IFF the shape of the micrograph is a geometric projection of the shape of the sample scanned in producing the micrograph" (Perini 2005a, 280). Figure 2 is a sketch of her view.

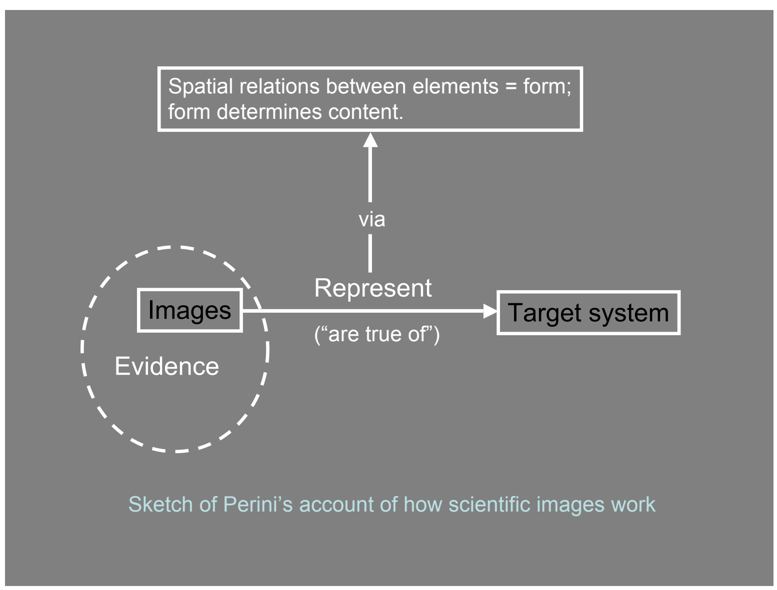

Figure 2. Stephen M. Downes. Sketch of Perini's account of how scientific images work.

Perini (2005a; 2005b) takes a slightly different tack when she tackles the role of images in confirmation. Again she deploys the symbolic view of representations. Visual images in science represent in virtue of their "spatial features that are interpreted to mean something about the[ir] referent"

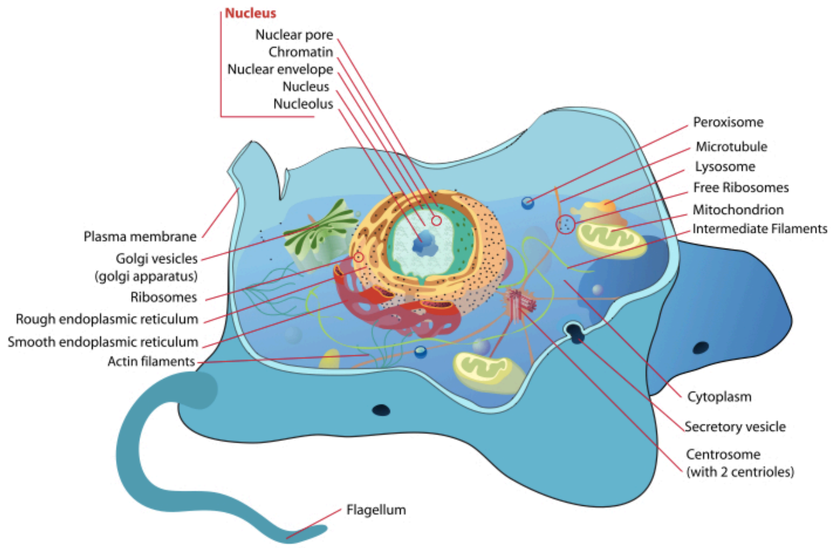

Figure 3. Ideal cell drawing.[1]

(Perini 2005a, 914). She continues: "Other visible features like color may also contribute to the meaning of visual representations, depending on the system, but the referential role of spatial relations is the defining feature of visual representations. Because of this, the visible forms of visual representations are related to their referents" (Perini 2005, 914). For pictures, like micrographs, the following is needed to secure their role in the confirmation of scientific hypotheses: "the causal relation between visible form of the micrograph and the structure of the sample is a source of the credibility of the representations that are produced, and allows for representation of novel and complex phenomena" (Perini 2005a, 921). Spatial relations make a definitive contribution to confirmation that linguistic representations of the same phenomena cannot make and images are causally "correlated" with their referents and, as a result, play a similar role to observations.

Along the way, Perini introduces some useful distinctions. One that I will refer back to in more detail is her distinction between schematic diagrams and compositional diagrams. Schematic diagrams include pictures of an ideal cell or ideal cell type (see Figure 3). There is no attempt in this type of diagram to present in detail one particular cell, for example, as viewed through a light microscope. Compositional diagrams include the familiar images in molecular biology texts such as presentations of the double helix (see Figure 4). These diagrams are used to show the components of a system, say a strand of DNA, and aspects of how that system works, in this case the appropriate nucleotide

[1] "Animal cell structure" (2006) from http://en.wikipedia.org/wiki/File:Animal_cell_structure_en.svg. Creative Commons Attribution-Share Alike 3.0 Unported license.

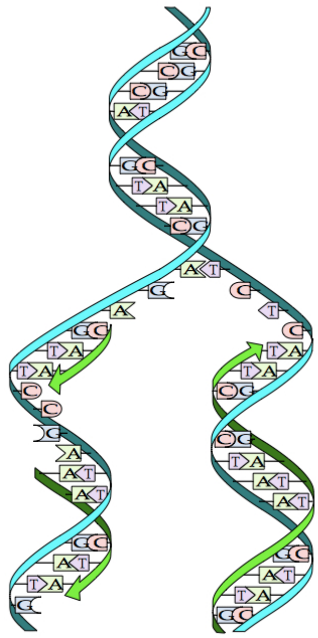

Figure 4. DNA replication diagram.[2]

pairings are emphasized. Perini's view and the useful distinctions that arise from developing her view can only arise from careful work on specific examples from scientific practice.

Overall, Perini's view requires us to view images as having a distinct form (in Goodman's terms, they are distinct symbolic systems) that sets them apart from linguistic representations. Understood this way, scientific images have an important, independent epistemic role to play and this role can be cashed out in terms of her theory of how images represent. In what follows I challenge this latter component of her view in a number of different ways. First, in order to develop some of these challenges, I turn to some recent work on another set of scientific images: Adina Roskies' (2007; 2008; 2012) work on fMRI images.

V. Are scientific images all direct representations?

Roskies (2007; 2008; 2012) has recently argued that certain images in neuroscience should not be treated as "photographs of the brain." She makes this case partly because most of us *do* treat neuroimages such as fMRI images as photographs of the brain (see Figure 5). Roskies argues that this is a mistake. According to Roskies, some scientific images are photographs in the most straightforward sense and do function as direct evidence (proxies for

[2] "DNA replication split" (2007) from en.wikipedia.org/wiki/File:DNA_replication_split.svg. Creative Commons Attribution-Share Alike 3.0 Unported license.

observations) (see Figure 6). Roskies introduces a useful notion for assessing the evidential power of images: a scale ranging from inferential closeness to varying degrees of inferential distance. Applying this scale, the birdwatching photograph (Figure 6) is inferentially close to its subject matter. Roskies relies on some machinery from Kendal Walton in aesthetics in her discussion of photographs, agreeing with Walton that photographs like this allow us to "see through" to their objects (Walton 1984). Photographs are more or less direct representations and share many properties with their objects. Obviously there is a huge range of photographs and photographic techniques, some of which produce images that are not direct in this way, but these points seem applicable to the bird photograph (Figure 6) and its ilk.

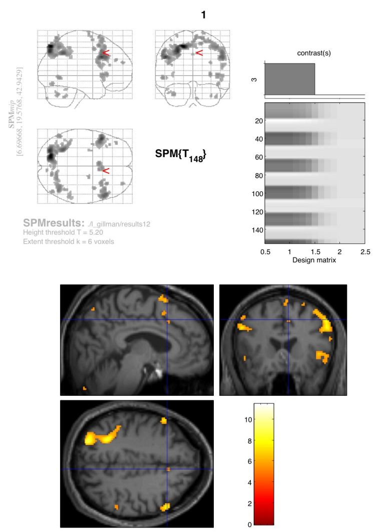

Figure 5. fMRI image. Courtesy of a Scanning Lab at the University of Utah. fMRI image.

In contrast, neuroimages such as the fMRI images (Figure 5) are inferentially distant from their objects. Roskies is careful to point out that her claim is very local and that the inferential distance in question arises from the specifics of how these particular images are generated. Briefly, the apparent picture of the brain we see in fMRI images is produced by combining thousands of slices of the brain into one composite 2-D (or sometimes 3-D) image. The image we see is the result of this process plus a great deal of statistical manipulation. Roskies does not deny that neuroimages of this kind have an important role to play in neuroscience but, crucially she does deny that they photograph or depict the brain in any standard sense. As a result, such images should not be viewed as proxy for direct observations nor should their epistemic role be accounted for via direct representation (see Figure 7).

Figure 6. Bird photo. Stephen M. Downes.

Roskies goes on to add a general observation about images: images are seductive because we are such visual beings. All sighted humans interact with our world via vision more so than any of the other senses. When an image is presented to us, we automatically think that it tells us what something looks like. Roskies adds that this disposes us to think of images in "photographic" or direct representational terms. As her argument implies, to follow this instinct in the case of many scientific images can lead philosophers to a mistaken assessment of the epistemic role of images. Before turning to more general issues about the roles of images in science I want to briefly present Roskies' case as a response to Perini as a way of showing that this gets us to part of what I want to conclude about scientific images.

One thing Roskies and Perini agree on is that images play some sort of evidential role in science. Also, they both agree that some images have a more direct and clearer relation to their objects. I agree that one role of scientific images is clearly evidential: they can act as proxy observations, but, even in straightforward seeming cases, problems can arise. Looking at another image, taken from Sarah Bush and her collaborators' work on avian lice, helps exemplify this point (see Figure 8). Bush et al.'s conclusion is that their "results suggest that background matching coloration has evolved in feather lice in response to host preening" (2010, 534). They also find support for the more general conclusion that host-mediated selection has led to diversification among many ectoparasites whose hosts carry out some kind of grooming. The images Bush et al. use are evidential in the most straightforward way: closest to photographs

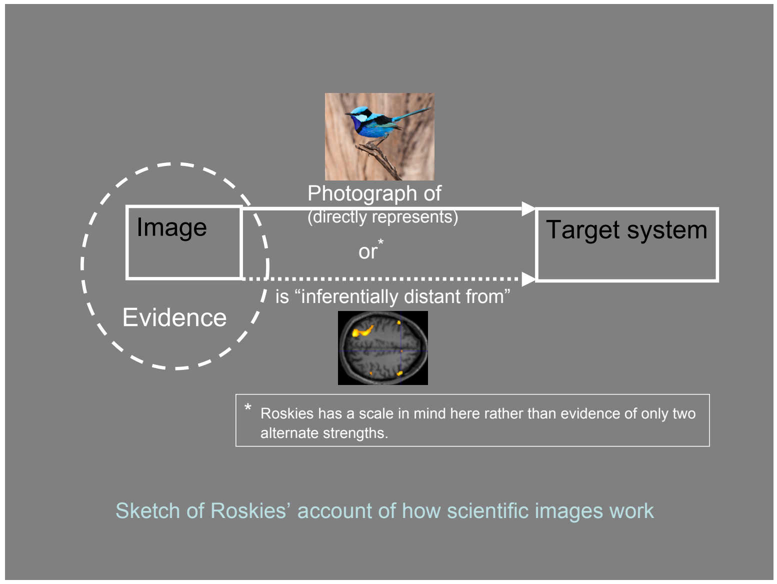

Figure 7. Stephen M. Downes. Sketch of Roskies' account of how scientific images work.

in Roskies' terms—they are photographs! Part of Bush et al.'s work involves photographing the various bird lice under exactly the same lighting conditions and comparing their color. The two different types of cockatoo lice are strikingly different but the researchers made efforts to find other patterns in louse coloration, for example, whether different colors are continuous or discrete within species. There is a clear role for such images as proxy observations in the sciences. Even in cases such as this though, I am skeptical that the relevant images are susceptible to a Perini-style analysis; how they do their work for the scientist does not seem to be accounted for in her spatial relations view of content determination.

As we have seen, Perini stresses the role of spatial relations between elements of images in determining their content. Recall that Perini (2005, 914) says that color may play a role in the way images work, but that the "referential role of spatial relations is the defining feature of visual representations." The relevant colors in the Bush et al. work are not particularly elaborate—almost black and near white—but they are the key variable being presented in the images. This point at least calls for an extension of Perini's approach to colors but conceding this may lead to more problems for her. Roskies' point that photographs represent via reproducing many of the properties of their objects is worth bearing in mind here. If we want to capture the way in which scientific images, such as the one Bush et al. use, work in the sciences, we need to bring in the role of color. As I said, the colors in this case are not elaborate. In other

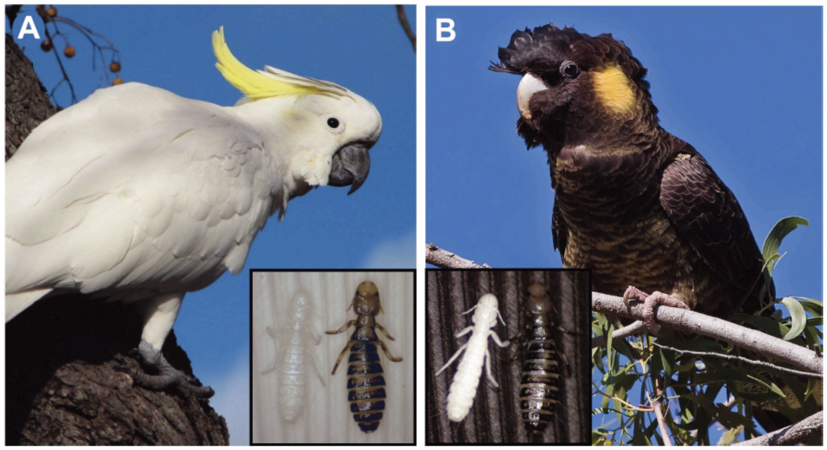

Figure 8. From Sarah Bush, Dukgun Kim, Michelle Reed, and Dale H. Clayton. Cockatoos and Cockatoo Lice

areas of neuroscience, work leading to the production of the image illustrated in Figure 9 color is very important. A huge amount of time and effort goes into making different fluorescent dyes bind to different cell types and organelles. This process of color labeling is the way that data is retrieved from these experimental systems. Perini's account, relying heavily on spatial relations, may lack the dimensionality to account for the work done by a large number of color images in science.

Roskies' work brings up a further issue about the relevant players in the proposed symbolic system contained by scientific images. She has a different take than Perini on what we should take away from the causal correlation between images and their objects. Perini and Roskies clearly agree that the appropriate causal correlation between images and their objects is key and both see a scale going from straightforward photographs and diagrams on the one end to micrographs and fMRI images on the other; their interpretations of this scale are quite different. For Perini, images such as micrographs can be shown to have content, determined from spatial relations between their elements, that allows us to see them as representations of their objects. Roskies' argues that fMRI images are far too "inferentially distant" from their objects to support the view that the images represent that object. This implies that learning about the causal process of producing these kinds of images does not support the idea that the spatial relations in the image reflect corresponding relations in their objects.

You could object that this last move is a little unfair, because fMRI images are not micrographs (the images Perini focuses on). Fair enough, but careful attention to the way many images are produced in science reveals that they do not all function as proxy observations or as photographs of parts of the natural world. I do not have in mind deliberate misrepresentations of states of affairs

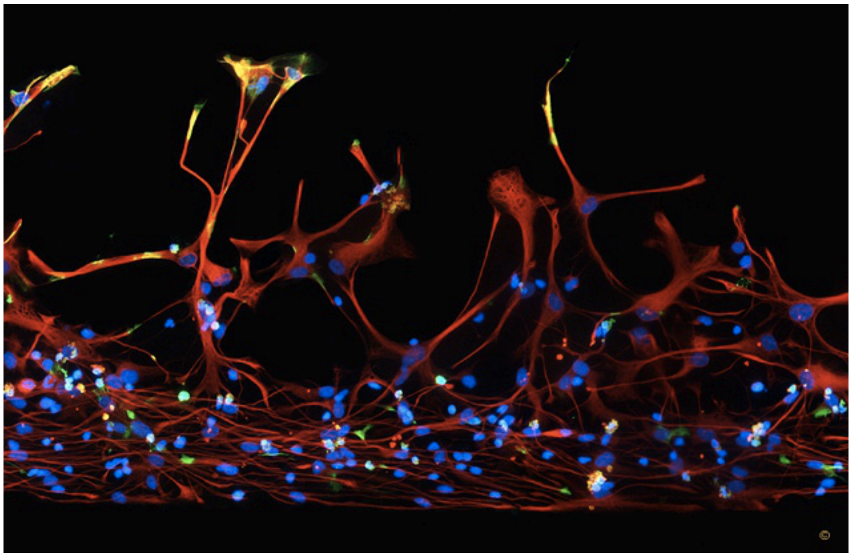

Figure 9. Photo taken by Cynthia Levinthal at Q Therapeutics' lab. Neoroscience image.

here either. Carefully photoshopping in a missing wedding guest in a wedding photo is a causal process that results in an image that does not accurately capture the original scene, but this is not the kind of causal process that usually goes on in scientific images' production. Many scientific images are carefully constructed and, due to the visual seduction Roskies talks about, we take these constructed images to look like their assumed objects. Scientific images are constructed via manipulation of both the image product and the source. As Roskies shows in the case of fMRIs, there is a huge amount of processing that goes into presenting the relevant signals in a form that looks like a picture of the brain. fMRI's are not an isolated case: to produce the image of activities in neural cells (Figure 9), many individual micrographs are taken of many tissues, each stained with different fluorescent dyes. Further work goes into manipulating the depth of the sample of tissue used. The resulting image may have the appearance of being a picture of a cell or part of a cell, but it functions to reveal or display the relevant data to the scientist. Images functioning this way are better understood as having a similar role to graphs. We rarely think of graphs as revealing the spatial relations between objects in the world; rather, we understand them as a way of presenting relations between data points or proving a visual presentation of an equation. Focusing on the causal process that leads to image production does not reveal the smooth continuum that Perini indicates it should. Instead it reveals roles of images other than the direct representation of processes, systems, and mechanisms in the world. So some scientific images seem not to represent on Perini's terms.

VI. Images, Models, and Representation Relations

In my discussion so far I have, along with Perini and Roskies, taken images to play an evidential role. I now want to look at other roles that images can play in science that is not evidential in any straightforward way. I begin this discussion by returning to Perini's distinction between schematic and compositional diagrams and then introduce some of the insights from recent work on models to support the conclusion that many scientific images are not best understood as direct representations of their presumed objects.

Perini's distinction between schematic and compositional images is a useful one, but perhaps not for advancing her view that images resemble their referents. The DNA diagrams familiar in molecular biology are nice examples of compositional images (Figure 4). These images are schematic pictures of the salient parts of DNA molecules in the double helix model and many idealizations and assumptions are built into these diagrams. They do a good job of illustrating some of the key features of DNA, but are a long way from a picture of a DNA molecule *in situ* in the nucleus of a cell. These kinds of considerations are among those that incline me to refer to such diagrams as model descriptions (or part of the model description). This claim derives from the recent work on scientific models I introduced earlier. It is pretty uncontroversial among philosophers of science working on models to hold that some scientific images are model descriptions or key components of model descriptions. Godfrey-Smith (2006), for example, says that model descriptions can be mathematical formulas, words or pictures. The notion of a model description comes originally from Giere and has been developed and elaborated upon by Michael Weisberg (2007; forthcoming) and John Matthewson (2012), among others. If scientific images do play this role, their content is not determined via a relation between spatial relations in the image and relations between components of a system in the world.

I also hold a stronger and more controversial view: some scientific images are models themselves. For example, I have argued that iconic schematic diagrams, such as diagrams of the animal cell (such as Figure 3), are models (Downes 1992). Giere (e.g. 1996) holds this view too, but he holds it for different reasons than I do. The connection he sees between images and models is their shared mode of representation. When the relevant image is what scientists use to further inquiry into an area and the image does not stand for or abbreviate a set of equations or clearly describe or specify another model, I take the image to be a model. Images that I take to be models and images that act as model descriptions do not constitute evidence in any familiar sense of the term. They play a very different role in scientific inquiry. When dealing with the presentation of models via images or the construction of images as models, scientists engage in a process not that far removed from mathematical model building. Sometimes the aim of the construction process is to represent part of a system in the world, but just as often the aim is quite different. The image can stand for a highly abstract, postulated process or system, which may ultimately help explain the way systems in the world function. It is in this attenuated sense that I want to say that some scientific images do not represent parts of the world. As a result, the epistemic work images do cannot be accounted for via an account of representation that characterizes relations between images and objects in the world.

My claim that some scientific images are models is not the consensus view, but many agree that the model/image boundary, just as the model/equation boundary and the model/object boundary, is blurry. Many define models narrowly enough to avoid these worries, but if you are more liberal about what counts as a model, as I am and many scientists are, these worries abound. As I have argued, I do not agree with Perini that we can secure one account of how all scientific images represent and use it to account for their epistemic importance in science. I do think that her distinction between schematic and compositional images is an important and useful one. Here though, I see the distinction as an important one to guide work on the blurred line between images and models in certain areas of scientific practice, rather than contributing to her project of finding "truth in pictures." Working with scientists on the way in which scientists use specific schematic and compositional images will help further our work in this area. I predict that this work will multiply our accounts of the way in which scientific images contribute to science, rather than support a unified view of the epistemic work scientific images do based on one account of representation.

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