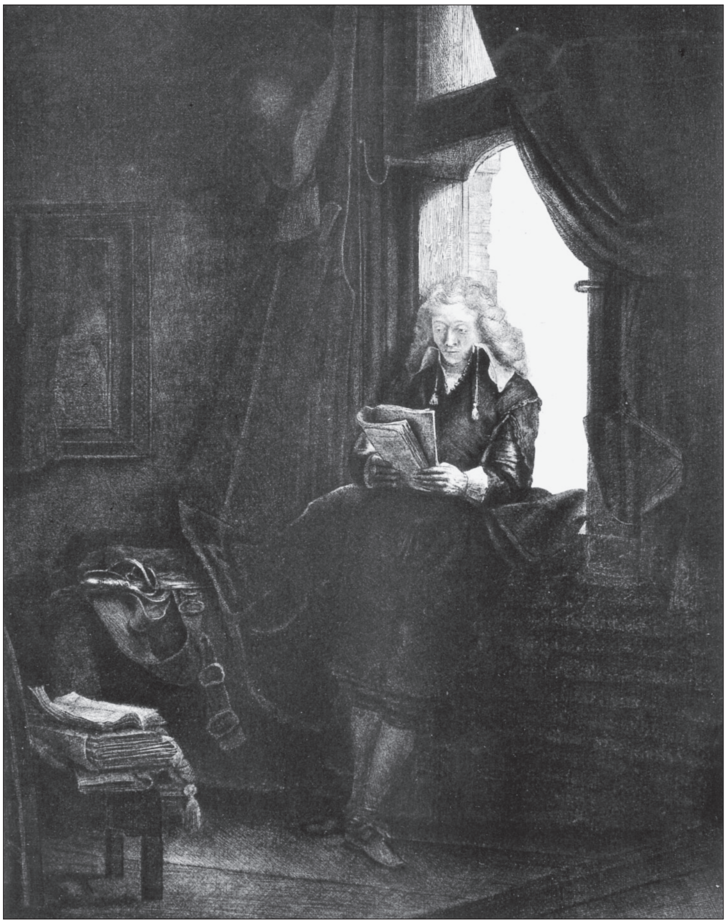
seem most thoroughly visual among the humanities. Art history and its intermittent companion studio art do take visual objects as their principal subject of study, but that does not mean that they visualize those objects *economically.* It is easy to demonstrate that art history and studio art use visual objects that are more detailed than the disciplines can accommodate. Their excess visuality is a remainder, left untheorized or even unremarked.

Consider this nineteenth-century photoetching made after a print by Rembrandt.



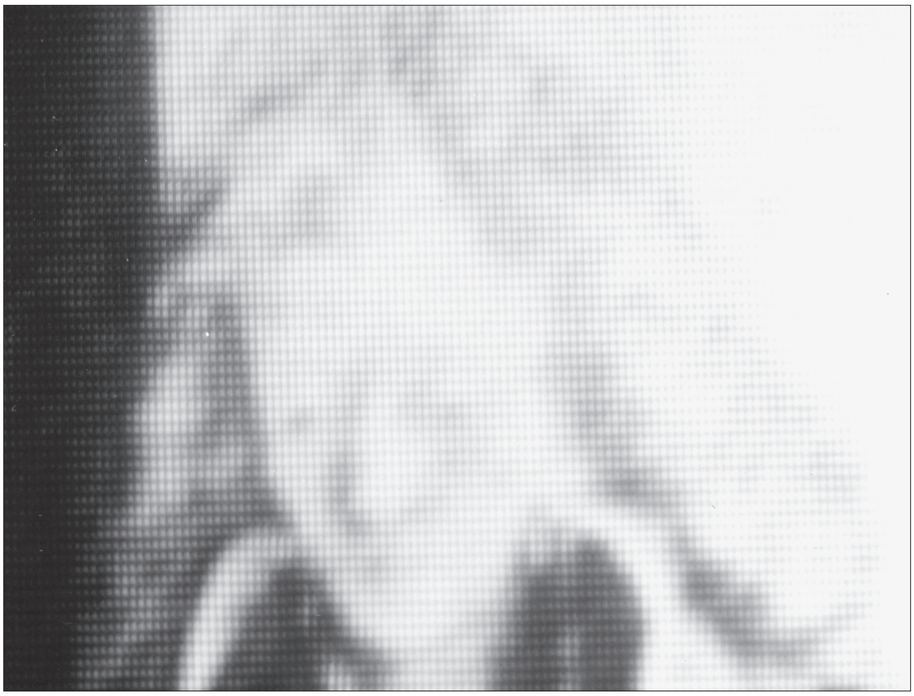
Photoetchings have virtually the same detail as original prints; a teacher of mine once told me some Prints Rooms in museums used to bring out photoetchings to test novices. (If the young historian didn't know the difference between the photoetching and an original print, she would only be given photoetchings from then on.) For these purposes the photoetching has the full detail of an original impression. Plate 8 is a detail of it.

The next three plates show, in order: the best available reproduction in a book; the view a student in the back of a seminar room would have of the best slide of the print from the slide collection of the University of Chicago; and the best available image on the internet, which in many cases is all a student might be able to find.

The second-to-last picture was taken in a darkened seminar room, from a seat toward the back, so it is a reasonable representation of what a student would see.

The salient point here is that none of these images, except perhaps the last, would be an impediment to any of the existing art historical accounts of the print. What art history says about visual objects is routinely far less than what is contained in the objects. In a sense that's a truism, but it also points to a kind of excessive visuality, which itself has a value even if it is not articulated: in art history it means, roughly, that the objects are art.

Other disciplines are both strongly visual and also maintain a closer correspondence between the content of images and the content that is understood to be



significant. Here the preeminent field, as I write this in summer 2006, is probably the study of protein folding. It has only been possible to visualize molecular folding for ten or fifteen years, because of the computing power that it requires. Now some truly amazing films have been produced showing, frame by frame, the calculated positions of some very complex molecules. (At this point books are no longer the optimal medium, and I will be pointing to several URLs and laboratories rather than reproducing individual frames. It is best to read this with a computer at hand, and see the films for yourself.) The visualization of molecular movements began in the 1980s, when it became possible to calculate the static properties of molecules such as electron density surfaces. Some sophisticated versions of those early graphics, transformed into movies, are now routinely available.[23] The new movies reveal molecules as twitchy, shuddering things, not at all the way they had seemed in the many elegant and unmoving "ribbon diagrams" of older textbooks.[24] At the most sophisticated levels, distributed computing has made it possible to make animations of the folding of large molecules like t-RNA. Such molecules fold in thousands of similar ways, and by sharing the calculations across a number of computers, researchers have found the commonest path from unfolded to folded molecule.[25]

Protein folding animations preserve a closer correspondence between forms in the images and forms that are analyzed, simply because each "ball" or "stick" or "ribbon" (each component of a molecule in the animations) is calculated. In the art historical example, the sitter's hair and wrinkles, the texture of his clothes, and the play of light and shadow, are taken to be outside the purview of the discipline.

Massive, computed visualization of proteins is different from what is taking place in other disciplines that are equally entranced with the visual. Astrophysics is one such discipline, and another is the electron microscopic imaging of individual atoms. Both are concerned with the limits of what can be resolved using their instrumentation. Chapter 12 compares images of the Galactic center over the last thirty years as astronomers have looked more and more closely at the tiny area just around the very center of the Galaxy, where a number of stars orbit a black hole. Chapter 6 is about one of the current limits of resolution in astronomy, an ingenious technique that allows astronomers to exceed the theoretical limits of resolution of their telescopes and visualize the dynamics of binary stars. The imaging of individual atoms using various kinds of electron microscope is another example of imaging technologies that are concerned with the limits of instrumentation, but there is an interesting difference. Still images of atoms in crystal lattices can be fairly sharply defined, almost as if the atoms are little billiard balls and the pictured are just a little out of focus. But the laws of quantum mechanics make it impossible to sharpen the blur, whereas in astronomy it is always possible to imagine larger telescopes.

Movies of individual atoms can be wonderful to watch. The pixellated blurs that show the positions of the atoms — or, in other cases, the smoothed bumps that stand for atoms — move in and out of visibility, like soft little stars. In some movies atoms race around after one another, twirling under the influence of mutual attraction and speeding apart when repulsive forces become stronger.[26]

One of the masters of this medium is Jan-Olov Bovin of Lund University; his films show individual gold atoms hovering over the surface of a gold crystal, shifting in and out of visibility, as if they were thinking about landing on the crystal.[27] Again I hesitate to reproduce individual frames. In the hands of the best technician, like Bovin, the movies are strange and compelling.[28]

I have briefly opened four questions within this first theme, just to show how rich it is. Within the question of how much of the world is understood to be visual, there are also the questions of the non-visual nature of the humanities; the unthematized, excess visuality of disciplines like art history; the profligate visuality of fields such as molecular biology; and the interest in the limits of visuality in fields like atomic physics. When I said that genuine theoretical progress can only be made by paying close-grained attention to the languages of different disciplines, this is what I meant: whole books could be written about each of those four sub-themes.

2. *Abuses of the visual.* Sometimes images accompany research papers, conferences, and textbooks, even though they are not used to support the science. In some fields images are customary; they are made habitually, and their absence

would seem odd. As the exhibition developed, it became clear that a fairly high percentage of the production of images across the university was of this kind: images were expected, but it wasn't always clear what function they fulfilled. I call these occurrences "abuses" just to give them a provocative label: I don't mean that images are used wrongly, just that they are unexpectedly *not* used, or used for unexpected purposes given their contexts. I will distinguish four kinds of abuses: visualization that is habitual, compulsive, forced, and useless.

Habitual visualization. A good example of the first is Chapter 24, which explores a blue and white image of the proteins in Cheddar cheese. The scientist who sent me this image, Paul McSweeney, at first thought I would use it as it was, without much explanation. If I had, it might have become one of the "beautiful" images that are thought to communicate some of their content simply by their aesthetic appeal. We wrote back and forth about his image, and it emerged that his laboratory does not always make such images, even though his research was on the subject of proteins in cheeses. Much less "beautiful" versions of the image are good enough for research purposes, and in fact they do not even need to be dyed blue. But every once in a while the lab needs a "beautiful" image to advertise itself. Gel electrophoretograms, as they are called, are a stock-in-trade of such laboratories; they are made for the posters scientists display at conferences, for teaching, for the covers of scientific journals, and for publicity inside and outside the university.[29] Labs that use gel electrophoresis are typically capable of producing these more "beautiful" versions of their ordinary images on demand.

In this book another instance of habitual visualization is in Chapter 8, which describes a software package called Nagios, used to keep an eye on computer systems like those found in large companies. Nagios normally runs in the background, but if there is a problem with one of the company's servers or with its internet connections, the full-screen view gives information about each component of the network. One of Nagios's selling points is its "3-D" view of a network, which displays servers and computers connected to one another by a web of lines, rendered in simple perspective. David O'Byrne, the computer scientist who introduced me to this software, said that he doesn't actually use the 3-D view. He prefers the tabular view or the 2-D map because when there is trouble, they give more information than the 3-D view. Nagios sells in part because of its capacity to produce useless, "pretty" pictures. In this case as in the Cheddar cheese images, visualization is habitual or customary, but not necessarily pertinent.

Compulsive visualization. My little encyclopedia of electrical technology is full of pictures that seem to have been made under a nearly incomprehensible compulsion to picture everything. One page offers vignettes of different kinds of "shops": machine shops, erecting shops, pattern shops, repair shops (see the illustration on the next page).

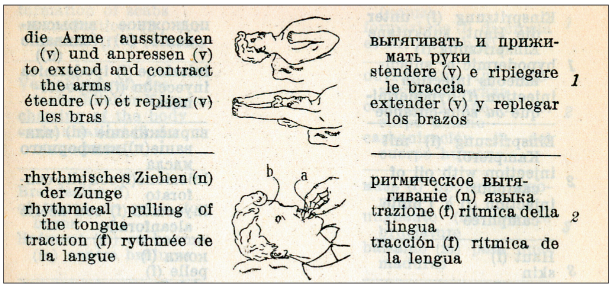
I can't recognize anything in them except a few workbenches. I wonder for whom these could possibly be useful: if I had an intimate knowledge of German


4 Maschinenwerkstatt (f) machine shop atelier (m) de construction de machines — машинная (механическая) мастерская (f) officina (f) meccanica taller (m) de maquinaria

5 Montierwerkstatt (f) erecting shop atelier (m) de montage — сборочная мастерская (f) officina(f) pel montaggio taller (m) de montaje

6 Modellwerkstatt (f) pattern shop atelier(m) de modelage — модельная мастерская (f) officina (f) dei modelli taller (m) de modelos

7 Reparaturwerkstatt (f) repair shop atelier (m) de réparation — ремонтная мастерская (f) officina (f) di riparazione taller (m) de reparación

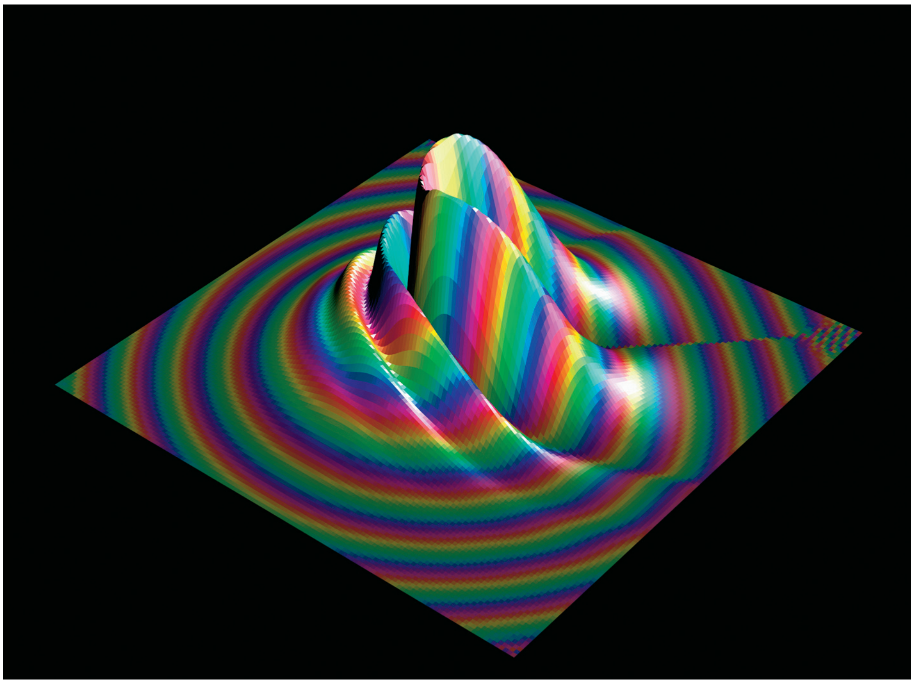

die Arme ausstrecken (v) und anpressen (v) to extend and contract the arms étendre (v) et replier (v) les bras — вытягивать и прижимать руки stendere (v) e ripiegare le braccia extender (v) y replegar los brazos 1

rhythmisches Ziehen (n) der Zunge rhythmical pulling of the tongue traction (f) rythmée de la langue — ритмическое вытягивание (n) языка trazione (f) ritmica della lingua tracción (f) rítmica de la lengua 2

machine shops in the 1920s, then I might find it helpful to compare the pictures of different shops, but somehow I doubt it. My favorite section in the encyclopedia is the one on first aid, which includes pictures of a man who has fainted, together with instructions on how to extend and fold his arms in order to revive him, and even how to pull his tongue.

I have no idea why it was considered helpful to pull an unconscious person's tongue, but the encyclopedia shows how to do it, and even labels the tongue and the man. The compulsive production of pictures is — one might argue, following for example Jean Baudrillard — a feature of late capitalism in general, but its disciplinary forms have not yet been studied. It occurs in this book in several forms; the most intriguing is Chapter 19, where a mathematician shows how to solve a problem once posed by Lewis Carroll using a series of graphs. His effort is part of an on-again, off-again tradition of visualizing mathematics: Should mathematical truths always be susceptible to being visualized? Or is the truth non-visual, and images its ornament? It's a foundational disagreement, played out most lucidly in mathematics. The mathematician who devised the visual solution to Lewis Carroll's problem didn't need to do so, but he was interested in the possibility. There is a compulsiveness about some scientists' use of the visual, and a compulsiveness about other scientists' refusal of the visual. The project in Chapter 19 is too extensive to illustrate in this book — it ran to over fifty diagrams — but it effectively demonstrates that the problem can be solved using entirely graphical means.

By *forced visualization* I mean the habit of making pictures of objects that are non-visual because they are multidimensional or not susceptible to illumination. Quantum mechanics is the twentieth century's pre-eminent example. The objects it describes are famously outside of ordinary human experience and possibly of all spatial intuition. Paul Dirac, one of the most acute theorists of quantum mechanics, is often quoted for his mistrust of images and his injunction to physicists to just "follow the mathematics" no matter how strange it might seem.[30] On the other hand there are specialists in quantum physics who do the opposite: they go on making pictures of quantum phenomena, despite the fact that they have to bend pictorial conventions to uses they had never had.[31] Bernd Thaller is the best example I know; he has written books and computer programs, and produced CDs of his visualizations. He makes pictures and movies of quantum effects, showing how particles exhibit wavelike behavior when they encounter objects.



His images are colorful because he symbolizes the phase of the wave equation by colors assigned to the complex plane: a positive real component is red, decreasing in chroma in proportion to its distance form the origin, a positive imaginary component is yellow-green, and so forth. I mention this for readers who may be interested; the salient point is that the colors are only one of several properties of the particle's wave equation. Other properties have to go unvisualized because it simply isn't possible to put them all into a picture or a movie. Most fundamentally, the wavelike objects Thaller visualizes aren't waves, but probabilities, in accord with quantum mechanics, and that basic difference is one of the reasons some quantum physicists eschew pictorial representation altogether. Everything about such pictures, it could be said, is a misleading analogy based on familiar, human-scale phenomena. Thaller is an optimist about representation, a complement to Dirac's pessimism. He is very inventive at bending the usual functions of pictures to make them express the maximum amount about the unimaginable objects described by the mathematics. He "forces" the conventions of pictures to express properties of objects that can never be seen — much less seen as waves or as color.

Useless visualization. In 1999 I visited a laboratory at the University of North Carolina at Chapel Hill, where a scientist named Richard Superfine was investigating carbon nanotubes.[32] He had several atomic force microscopes set up in the lab, trained on microscopic samples of the nanotubes. Sitting at a monitor, I saw a flat surface in perspective, with a wobbly form lying on it like a bent pipe. At my right, in front of the monitor, was a pen, attached by a series of bars and joints to the desktop. As I moved the pen, a cursor on the screen moved. The idea was that I could actually push the nanotube around on the substrate, and that when I made contact, the pen would push back, representing the force required to move the nanotube. The universal joint attached to the pen would provide force-feedback, giving me a kinetic sense of the object's tensile properties and the forces binding it to the substrate. Superfine's laboratory had several such microscopes, which they used to investigate the ways nanotubes bend, roll, and stack — the ultimate aim being to build structures with them, possibly even nanodevices such as nanobots. I asked for some scientific papers that set out discoveries made with the atomic force microscopes, and Superfine said there weren't any — that his results came from other experiments. That surprised me, and I asked what the force-feedback devices taught them. He said they kept a list of "aha!" moments, in which people in his lab had found unexpected properties of the nanotubes by pushing them around, but that none of those "aha!" moments had made it into a scientific publication. The microscopes were wonderful, he said, for getting a feel for the objects, and they were also popular with school tours. They helped publicize and promote the lab's activities, and they gave an intuitive grasp of the objects, but they did not produce science. The science came from more controlled experiments, in which properties such as tensile strength and compressibility could be quantitatively measured.

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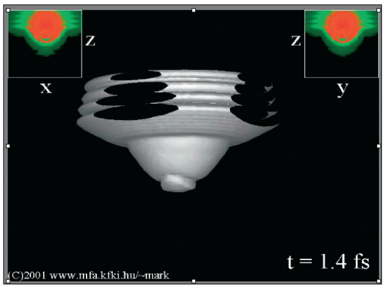
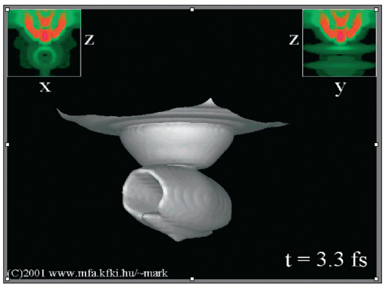
A "useless" image, in science, can be defined as an image that cannot be used to calculate, because it has nothing quantitative in it. Superfine's force-feedback setups are useless in that sense. There are also images that have quantitative information, but the experiments choose not to extract it. Instead the people who make the images are interested in them as visual examples of what their equations would look like. There are some spectacular examples in recent science. A Hungarian team produced a short film of a scanning tunneling microscope tip hovering over a carbon nanotube, just the kind of arrangement that Superfine's laboratory had.[33] In scanning tunneling microscopes, a sharp tip (the inverted cone at the top) senses the object, in this case a carbon nanotube (the hollow tube at the bottom). In practice, such a microscope would be used to produce a picture of the object — the nanotube — as if it were seen from above, and that is the way I observed nanotubes in Superfine's lab. In the Hungarian scientists' movie, what's under study is the microscope itself. The carbon nanotube is modeled as a cylinder 0.5 nanometers in diameter, and time is measured in femtoseconds. As the viewer watches, a slippery-looking sheet comes down over the tip and envelops the nanotube, as if it were a dessert being covered with liquid white chocolate.

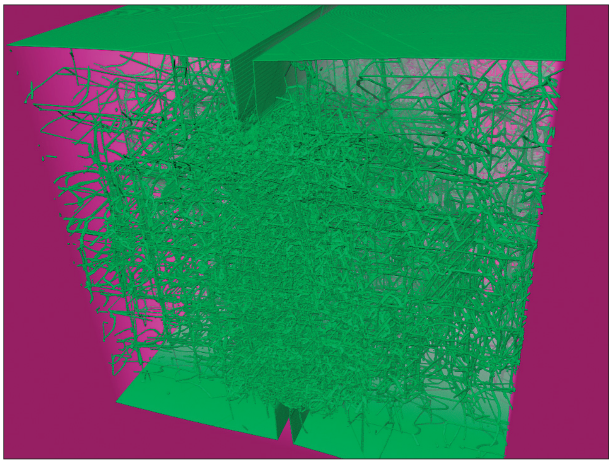


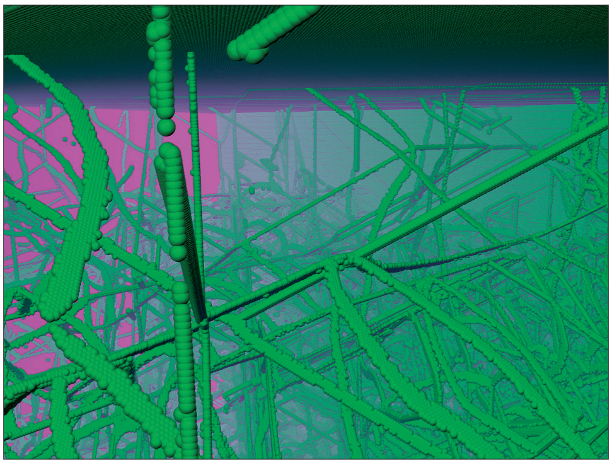


The white goo is the constant-probability surface of a Gaussian wave packet. It is an amazing visualization, and the mathematics behind it are pertinent for the design of such microscopes — but the film itself does not provide the analysis, only the visualization.

An even more impressive example is Farid Abraham's simulation of the motion of 1 billion atoms in a block of copper (see the illustration on the next page).[34] It is a film made to show the effects of putting copper under stress but not breaking it: the atoms shear against one another, producing dislocations throughout the block. The film includes several fly-throughs of the block, and viewers can watch as the dislocations spread like tendrils throughout the mass of copper.

(Atoms are only drawn if they are dislocated by the pressure: the film actually represents a solid block of a billion atoms, but the only ones shown are along shear lines.) Interesting as the film is, it only gives a qualitative idea of the tangle of dislocations; the science is elsewhere. It is useless, strictly speaking, because it serves more to capture viewers' imaginations than to disclose new properties of copper.





It might be said that the “abused” images in these four categories aren’t “useless” at all, because they serve political ends. They help laboratories and scientists advertise themselves, and they spark conversations about the work that may lead in new directions. That is true; the images are only “useless” in the sense that they themselves are not the proof or evidence of whatever scientific claims the laboratory is making. They are, instead, ornaments on the more fundamental work of experiment or mathematics. I called this theme “abuses of the visual” rather than, say, “images that are only political” because the word “politics” flattens the images’ different relations to scientific truth and utility. The politics of publicity, grants, careers, and publications certainly contributes to the production of “useless” and other “abused” images, but politics isn’t the whole story. In the humanities, and especially in visual studies, the politics of an image is nominally its most fruitful and constitutive property. Politics is taken to go, as Nietzsche said, "all the way down," and analyses can begin and end with the politics of image-making and image interpretation. In the sciences, politics plays a crucial role but it is not what the enterprise is all about. The idea of thinking about "abuses of the visual" is to shift the conversation a little so that these images cannot be so quickly explained as politically expedient.

A salient fact here is that the sciences, unlike the humanities, produce enormous numbers of images they do not directly use. To some degree these "useless" images are evidence that people associate truth with images, so that an image is a proof of veracity even when it is does not, strictly speaking, prove anything. It makes sense, I suppose, that such images are common in the sciences than in the humanities, where veracity and truth are so much to the point. It might be fruitful to study these "abused" images from this perspective, as remnants of the idea that images are truth. (One could ask, for example, what about each image seems to capture something true, even though that truth cannot be quantified or linked to the mathematics or the experimental data.)

Images that are made and discarded, made but not used, made but not valued, are ubiquitous, and one of the cardinal dangers of any study that emphasizes images is not noticing when the objects of study aren't valued by the people who make them. The field of visual studies, and in particular those scholars, centers, and departments interested in non-art images, are liable to make too much of what they study, and not to notice when the objects are eclipsed or forgotten. "Abused" images are also a reminder that it is easy to overvalue the objects of one's attention. Many of the pictures in this book are simply not important to the fields that produce them.

3. *What counts as a picture?* I have mentioned the fact that some images in this book look like naturalistic pictures, but aren't. The images in Chapter 12, for example, are "velocity graphs." In a normal, naturalistic picture of something — say, a galaxy — an object higher in the picture would be "higher" in space (perhaps in declination, to use the astronomical term), and an object to the right in the picture would be "to the right" in space (in right ascension, say). In Chapter 12, the two axes of the pictures do not represent position, but speed. The images look like ordinary photographs of astronomical objects, but they aren't.

Should such images be counted as pictures, or would it be better to call them graphs or — following the three-part division in *Domain of Images* — notations? Sonograms are another example. The song of the Canyon Wren reproduced in Chapter 8 looks like a picture of the bird's song, but of course it isn't: it's a graph of the pitch of the song as it changes through time. Readers accustomed to music notation will be able to "read" the graph in a general way, and see how the song drops down in pitch. It's the kind of song that people call "sad" or "plaintive." The sonograms of human speech reproduced in the same Chapter are harder to "read" but they are constructed the same way. It would probably be stretching

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the concept to call these pictures, but it would also be appropriate because they are constructed to look a bit like pictures. It often helps scientists to have images that behave *a little* like ordinary naturalistic photographs.

That extraordinary fact opens a new way of talking about such images. They are *picturelike,* and the right language for interpreting them should probably not be too far removed from the language that is used to interpret naturalistic images. If they were simply or purely graphs or notations they might well be arranged differently: without glowing colors, for example, and without higher tones being higher on the image. Those are pictorial conventions, borrowed from ordinary picturemaking. All sorts of different conventions would be available to image-makers who did not want to keep the residue, the hint, of ordinary pictures.

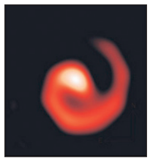
It is possible to distinguish several different kinds of images that are not quite pictures:

Picturelike graphs. The examples I have given so far substitute things like pitch, time, and velocity for the usual dimension of space. (A photograph is a space-space representation, to put it abstractly. A sonogram is a pitch-time representation, and the images of the galactic center are velocity-velocity representations.) Even the spectrum that opens Chapter 1 is picture-like. Its vertical axis indexes wavelength, and its horizontal axis is meaningless. (Aside from the film strips at the right and left, which are used for measuring.)

Multidimensional images. Chapter 16 reports on an aerial survey of Cork done with a specialized camera, like one later flown on a mission to Mars. The camera gathered a mass of data, which was used to produce aerial photographs that look just like old-fashioned aerial photographs taken with simple cameras. But those familiar-looking images were *extracted* from the mass of data the camera gathered, which could be used to generate all sorts of other images. The team that flew the camera over Cork used the fuller data set to study the height of buildings and to make a simulation of the flooding of the city. The data could also be used to identify specific crops, or distinguish fallow fields from planted ones, or to survey tree cover — there is a large potential range of agricultural, geological, engineering, and city planning applications. The aerial photographs are thin slices of a larger data set.

The same could be said of the 3-D laser surveys of inscribed stones described in Chapter 22, or even the encyclopedic map of the geology of southwest Ireland shown in Chapter 14. Both result in pictures that are only samples of the available data. This kind of thing rarely happens in the arts and humanities. The *Mona Lisa* is not an extract from some larger bank of images, except in the abstract sense that it has a history and a context, like any image. Artworks tend to display or contain the sum total of their information, but scientific images are sometimes just tiny portions of a larger invisible or unvisualized whole.

Frankenstein pictures. Then there are images cobbled together from many different sources, not all of them visual. A curious example is a film of the binary

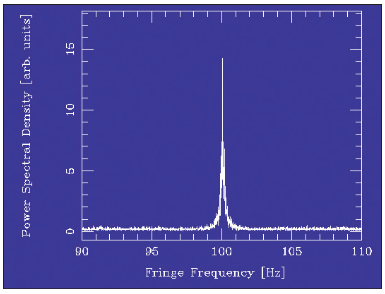


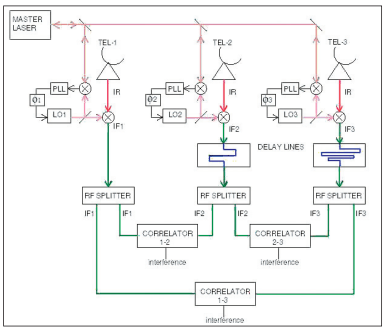
star system named Wolf-Rayet 104 (the name identifies one of the two stars in the system). The system, WR104, has been widely reproduced as a short film loop because of the very unusual fact that it looks like a pinwheel.

In the film, the spiral spins. The effect is caused by hot gases being thrown off of one of the stars in the pair. (Neither star is directly visible in the image.) The popularity of the film must be due in part to the surprise of discovering that somewhere in the constellation of Sagittarius there is a little pinwheel spinning.

Yet the film is really very distant from a movie of a pinwheel-shaped object. First, its "hot" red color is false.[35] Actually, it was imaged in the infrared, so this particular shape would be invisible to the naked eye. Second, this was never seen from a single telescope. It is an image constructed from three telescopes situated a small distance from one another in a field. Third (and most counter-intuitive), none of the three telescopes produced an image on its own. They each saw just one point of light at a time, and their signals were combined using interferometry. The combination of the signals of two of the three is shown below; that is a stage in the construction of the pinwheel image.

Fourth, the signals processed to make the image underwent a change known as *heterodyne reduction:* they were each combined with laser light, producing a single wave of a much longer frequency, which was then carried as a *radio* signal in wires. Fifth, the reduction was necessary because the signals have to reach the computer that analyzes them at the exact same time, and the telescope at one end of the field is actually a tiny bit father from the star than one at the other end of the field. To compensate, the signal from the closer telescope is sent through a longer wire. It seems implausible, but in this way the three telescopes are effectively exactly the same distance from their object (the folded wires can be seen in the schematic).





The pinwheel image was therefore built out of the signals from three telescopes, by heterodyne reduction, signal delay, interferometry, and false color: hardly an ordinary way to make an image.

Interferometry of this kind, which generates 2-D images, is both counter-intuitive and complicated, and although I have tried I cannot understand it in full. The deceptively familiar-looking pinwheel is a Frankenstein creation, made of disparate parts. There is nothing quite so elaborate in this book, although the images of inscribed stones in Chapter 22 are roughly equivalent. They begin as "point clouds" (sets of 3-D data points recording the shapes of the stones) and end, after many layers of processing, as apparently naturalistic images that are actually composites of surface corrections, 3-D manipulations, lighting routines, false color, and texture mapping. They seem to raise the same issues of realism as the computer-generated monsters in Hollywood movies — except that the images of inscribed stones, and the film of WR104, began with observations of real objects.

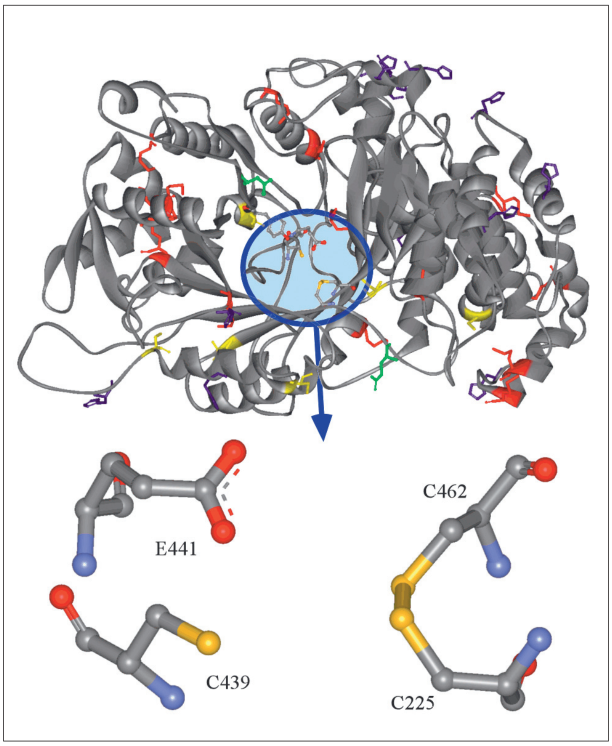
Picturelike graphs, multidimensional images, and Frankenstein pictures are examples of things that aren't really pictures or films in the conventional senses of those words. The aerial photograph in Chapter 16 is only a conventional picture if its matrix is ignored: really, it's a sliver of something larger, like the portion of a multidimensional geometrical object that can be represented on a piece of paper. The Wolf-Rayet star, velocity graphs (Chapter 12) and speech sonograms (Chapter 8) are picture *mimics:* they work, in part, because the mimic pictures.

4. *The thicket of representation.* This is a phrase coined by the biologist and philosopher William Wimsatt to describe the problem of making pictures of genes.[36] There are a half-dozen different conventions for making pictures of complex organic molecules, and no one of them is adequate by itself. Each gives a particular kind of information, and works at a certain level of detail. Ribbon diagrams of molecules, for example, do not quite reach to the level of atoms, but ball-and-stick models do (compare the top and bottom of the illustration on the next page).[37]

These two images cannot be combined into one image because they use different imaging conventions; it would be like trying to paste a picture of your house onto a map of your town. In scientific software these two conventional representations can be "toggled," but they can't be fused into one kind of picture.

This is another theme that is largely unknown in the humanities. A close parallel might be the existence of a painting and a drawing for the painting: the two can't be combined, but they have to be considered together in order to get the fullest idea of the artist's conception. The flaw in that parallel is that in most cases, the painting was intended to be the self-sufficient and authoritative version of the object; in science, all the kinds of representation in the thicket need to be considered together. The authoritative version of the object is not any one visual representation, but a conceptualization that involves a number of different kinds of images.

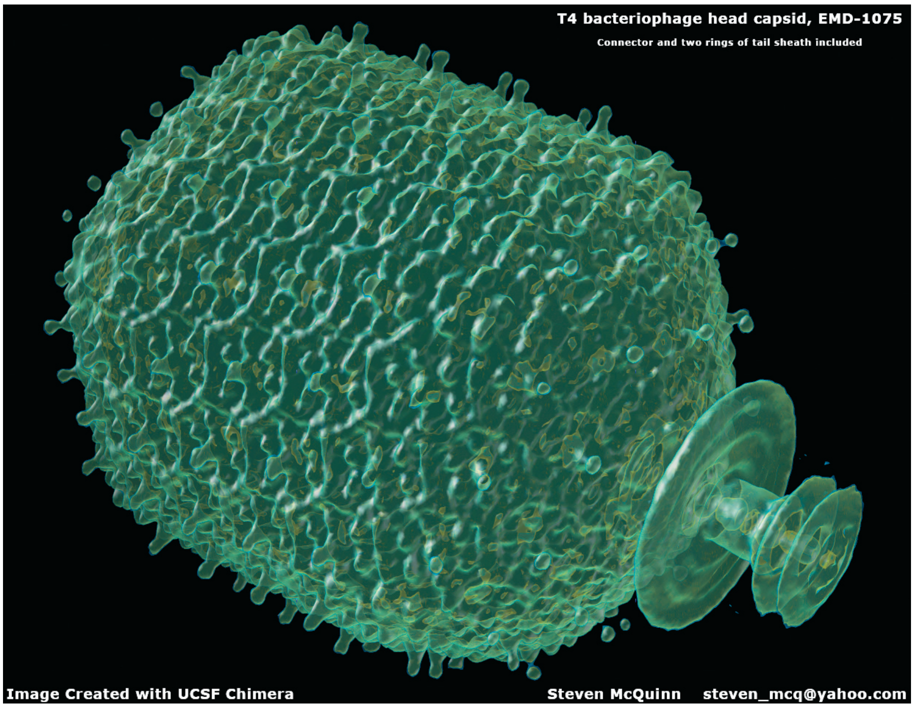
In this book, a good example is the visualization of bacteriophages in Chapter 27. The Chapter lists eight different ways of making pictures of bacteriophages. They vary tremendously, from ordinary close-up photography of Petri dishes to complicated graphics of individual atoms. More could be added to the list. I have



mentioned Hybrid Medical Animation's dramatic movies (see the illustration on p. 16). Another is Steven McQuinn's 3-D renderings of the head capsids of a bacteriophage; he uses translucent surfaces to make the subtlest structures visible (see illustration on the next page). (In Steven's case, the idea isn't to do science, but to tweak the scientists' assumptions about what subatomic objects might "look like." He intentionally uses translucent surfaces and ray tracing to make the viruses look like plastic bottles.[38])

There are also a few scanning electron microscope images of bacteriophages, and I could add life-cycle diagrams (a common feature of biology textbooks for at least fifty years), and even spectrographs.[39] On a rough count that is thirteen ways of looking at bacteriophages, although the number is arbitrary because most kinds subdivide into different types. A typical scientist might use a half-dozen in different combinations, toggling back and forth to compare them, and printing several side by side in scientific papers. The thicket cannot be cleared: it can only be negotiated.

In this book, you can explore the thicket of representation in most of the chapters. The exceptions are subjects where just one kind of image is optimal (Chapters 7, 17) or where images really aren't the point (Chapter 24). The arts, again, are the odd man out: Chapters 15 and 26 on fine art do not have competing images. Even ar-



chaeology, among the humanities, has a ferociously complicated repertoire of imaging types, many of which are used together to describe archaeological sites (Chapter 13). The thicket is the norm, and the isolated image of fine art is the rarity.

5. *Image quantification.* If there is a general, underlying expectation of images in the sciences it is that they contain what I call *propositional content.* It is expected that data can be extracted from them, that they contain measurable forms. A bar graph can be read immediately for its information, and so can the kind of supply-demand graph used in economics (Chapter 4). Other images have to be measured before information can be extracted from them; an example is astronomical images, which are read pixel by pixel to extract quantitative information. The analogue in the humanities would be images that are also writing, so they can be read as well as seen, as in Chapters 5 and 29. It is normal in the sciences to analyze an image in order to extract information, and anything that is left over is considered heuristic, decorative, "aesthetic," or "beautiful." A striking image can be a good thing, if it helps the image attract attention, but what matters is the content, stuff that can be used to calculate. It is more or less the opposite in the humanities, where propositional content in an artwork — themes, ideas — would normally be seen as an interesting part of the work, but by no means its central quality. The lack of interest in propositional content explains why art historians (I was one of them) were impatient with David Hockney's and Charles Falco's

explanations of the perspective and geometry of paintings: it wasn't that Hockney was wrong, exactly, but that his observations were beside the point.[40] John Heartfield's political collages, studied in Chapter 26, are not valued because of what they say about Hitler — many other people during the Weimar Republic accused the Nazis of similar things — but because of their visual form. It is the extra, what is taken as the visual contribution, that matters in fine art.

It is interesting to study how scientists, lawyers, doctors, and engineers search for propositional content. Often the tool is image-analysis software, which can outline objects of specified shapes, sizes, or colors. The geologist Pat Meere uses software to find the outlines of grains embedded in rocks (Chapter 23). The biologist Emer Rogan uses software to find the outlines of the fins of whales and dolphins (Chapter 25), and Marc Shorten uses similar software to trace the outlines of the wings of ducks and other birds (Chapter 18). All three outlining routines are different. Image-analysis software is ubiquitous in this book. It can also color-code objects of interest, such as frequencies in sonograms (Chapter 10) or crops in a field (Chapter 16). It can count objects, and even produce equations for their shapes (Chapter 23). In the humanities, there really isn't such a thing: it is only the sciences and allied fields where the quantification of images is important. Image-analysis software is a big and largely unstudied field; the major software packages, such as Exbem, NIH Image, and ImageJ, are virtually unknown outside the sciences. (Photoshop, the image manipulation software of choice in the arts, has only very limited image analysis capabilities.) Scientific image analysis software packages are the equivalent of the exotic kinds of diggers that are used in large-scale strip mining: they are the most efficient way to strip away the "aesthetic" and get at the informational.

It is fascinating that some image-making practices outside the arts continue to resist quantification. An example is mammography, which despite all efforts to automate it continues to require expertise and, as a necessary correlate, to be considered less than wholly reliable. In the mid-twentieth century the same was true of the diagnosis of chest X-Rays for signs of tuberculosis. Having been tutored in how to read X-Rays, I can say that it is definitely an art (that is, a skill that cannot be wholly taught) to spot the small white smudges that are the first signs of tubercular infection. They are hard to see, and hard to distinguish from vessels seen end-on. Experts in chest X-Rays and mammograms tend to be people who have practiced for years.

In this book the preeminent example is the physician Nollaig Parfrey's discussion of kidney diseases (Chapter 21). Parfrey is an expert on membranous glomerulopathy, a condition that is not easy to diagnose. It requires a series of images made using different image technologies — it's an example of the thicket of representation. Each image needs to be analyzed for qualitative, rather than quantitative, signs. The relative abundance of some forms, or the relative thickness of capillary walls, are clues. Only a few of the signs Parfrey looks for are