Peter L. Galison

Scientific Forms of Sight

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Zusammenfassung
In seiner visuellen Geschichte der wissenschaftlichen Objektivität unterscheidet Peter Galison drei verschiedene Formen des Sehens: Die Naturphilosophen des 18. Jahrhunderts wollten Dinge jenseits des Sichtbaren sichtbar machen. Diese »naturgetreue« Form naturwissenschaftlicher Anschauung bedurfte eines Genies, das hinter den Vorhang des Partikulären blicken konnte. Lediglich seit der Mitte des 19. Jahrhunderts sprechen Wissenschaftler von einer Objektivität, die unserem Verständnis von heute nahe kommt. Sie favorisierten mit ihrer klaren Grenzziehung zwischen künstlerischer und wissenschaftlicher Praxis die so genannte »objektive« Autorität der Beobachtungstechniken gegenüber der Subjektivität des menschlichen Auges. Mit den wesentlichen Neuerungen wissenschaftlicher Anschauung vor dem Hintergrund der digitalen Bildproduktion und Wissenschaften, die auf crowd-sourcing basieren, werden im 20. Jahrhundert Beurteilungen ausdrücklich Teil der Darstellung. Zum Ende seines Beitrages tritt Peter Galison in einen Dialog zu seinen Thesen ein.

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Stefan Apostolou-Hölscher, Diego Chamy, Alice Creischer, Alberto de Campo, Anke Eckardt, Adele Eisenstein, Anselm Franke, Peter L. Galison, Hans Ulrich Gumbrecht, Nik Haffner, u.a.

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Peter Galison

Scientific Forms of Sight[1]

Followed by a conversation with Eric Ellingsen

Over the last two hundred years the physical and life sciences have been engaged in an unending search for the best form of the "right representation" of nature – what has counted as "right" varied considerably over time. In the eighteenth century, Johann Wolfgang von Goethe indicated in a sketch in his notebook that he would not use any particular animal when he was drawing an insect or a particular plant when he was drawing a plant. Instead, he sought to capture the archetypal form (*Urpflanze* or *Urinsekt*) that lay behind them. Similarly, when the eighteenth-century anatomist Bernhard Siegfried Albinus drew a skeleton, he wasn't just idealizing in the sense of putting a dancing skeleton in front of a white rhinoceros. He was also idealizing by saying that "those things which were less perfect were mended in the figure […] to exhibit more perfect patterns".[2]

The task of finding the ideal form behind the vagaries of individuality or corruption seemed obvious to eighteenth-century scientists. This endeavor was part-and-parcel of what it meant to depict the natural world. Even when William Cheselden used a *camera obscura* to draw his skeleton hung upside down so that it would look right side up in the inversion of the lens, he still said, in so many words, "I'm going to fix the cracks, the defects in the skeleton". It was not just a matter of instruments, of technology, but also of a frame of mind, a form of sight in which the author-artist could extract the ideal behind the vagaries of individuality or accident.

Not just anyone could see past the individual specimen to the ideal behind it. The right kind of scientific self to depict nature was a sage or a genius. The right kind of image had the status of being metaphysical, that is, what the image referred to was a reality that one could not see except in the image. The associated practice was one of intervention, to fix things as much as one could. The ontological status of the thing depicted was that of a universal. The *Urpflanze* is not something you find in nature, no plant looked particularly like the drawings in Goethe's notebook. Rather, the *Urpflanze* is a metaphysical entity that is only partially realized in the many different species or plants that one might find in nature. Importantly, the aim of this form of "ideal sight" is truth. It involves the exclusion or not seeing of some things, namely the imperfections and idiosyncrasies of individual objects. These are filtered out, as it were, by the ontology of the thing represented, the practice of producing the image, and the presupposed scientific self. Only a sage could succeed at finding a truth to nature through idealization, producing

1 Editorial note: This text is a revised version of Peter Galison's Keynote held via video conference at the Syposium *Perception, Experience, Experiment, Knowledge. Objectivity and Subjectivity in the Arts and the Sciences* at Graduale13, the annual Symposium I curated at the Graduate School for the Arts and the Sciences at the Berlin University of the Arts, October 11th 2013. It was followed by a debate hosted by Eric Ellingsen, selected parts of this conversation close this contribution.

2 Bernhard Siegfried Albinus: *'Historia hujus operis'*. *Tabulae sceleti et musculorum corporis humani* (Leiden 1747). Translated as *Tables of the Skeleton and Muscles of the Human Body* (London 1749), sig. b.r., quoted in: Lorraine Daston and Peter Galison: *Objectivity*, New York 2007, p. 74.

the universal. When this process of idealizing depiction is complete, no particularities appear on the page. This form of sight (and as we will see, every other one as well) obscures some things and illuminates others.

Not until the middle of the nineteenth century scientists did begin to talk about objectivity in something like our sense. One might call this form of objectivity, as Lorraine Daston and I have done, mechanical objectivity.[3] Mechanical objectivity does not boil down to the instruments used – tempting as it might be to make objectivity the output of an analog camera, that will not do. Rather, mechanical objectivity is a way of coordinating the observer and the thing observed. So the German physiologist Otto Funke, who made physiological crystals and crystallized blood and other bodily fluids, knew that the microscope distorted the image in various ways (for example by chromatic aberration or by allowing one crystal to alter the appearance of an image behind it). Nonetheless, he insisted over and over that he would draw what he saw in a way that was faithful, showing his conscientiousness by drawing "even the deceptions". Funke knew the edges of the visible field in the microscope only appeared to be yellow – that didn't stop him from reproducing them in his illustrations.

Now, if Goethe could have heard this, he would have rolled over in his grave because it would have seemed patently absurd to draw something known to be false. The whole idea for Goethe, Cheselden, Albinus and other eighteenth-century natural philosophers was to depict the things beyond what one could actually see, to find truth behind particularity. In the mid-nineteenth century, this changed. For instance, in several of Funke's images there is some yellowing in the lower bottom that is just an artefact of a bad lens. Funke knew that but he drew it anyway because he felt his job was to be a faithful transmitter of what he saw, in a sense, to become transparent. So his moralized sense of obligation to be faithful, conscientious, and to depict even things he knew to be false, was part of a new form of self that was to be identified with this objective scientist of the nineteenth century.

We see this tension between two forms of sight (idealizing and mechanical) in a battle that took place between two neurophysiologists, Camillo Golgi and Santiago Ramón y Cajal, one Italian, the other Spanish, who shared the Nobel Prize in 1906. Golgi declared at the ceremony, "I have prepared these images according to nature. They are less complicated than in nature, they are semi-schematic".[4] So when we read that today, we think: "How can that be? Isn't that oxymoronic? How could something be prepared according to nature but be less complicated than nature, even semi-schematic?" What he meant was that he was drawing not on the basis of a text or the accounts of others, but he was seeing through an older form of sight: idealization, correcting by what he knew to be the case. And what he knew to be the case was that the brain was one interconnected net whereas Cajal thought that the brain was made up of almost independent neurons. So when Cajal watched Golgi project these slides at Stockholm at the Nobel Prize ceremony, Cajal reported that he became almost physically sick. He was so angry

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3 Lorraine Daston and Peter Galison: *Objectivity*, New York 2007.
4 Camillo Golgi: "The Neuron Doctrine – Theory and Facts", in: *Nobel Lecture*, December 11 (1906), online at: http://nobelprize.org/medicine/laureates/1906/golgi-lecture.html (last accessed January 28, 2014).

he could hardly sit in his seat. He found Golgi to be engaged in a wilful, theory-driven distortion of what was in front of him. This contrast between Golgi and Cajal captures a battle still being fought in 1906 at the Nobel level between two forms of sight: one idealizing and one struggling for self-restraint. Truth to nature versus mechanical objectivity: one directed by will, the other by a will to will-lessness.

Yet a third form of sight enters the story in the twentieth century, when scientists begin to chafe under what they perceive as the dangerous restrictiveness of mechanical objectivity. Many come to think that the slavish constraint to put in the figure all that emerges from the image-making apparatus risks publishing visual artifacts or publishing images that obscure the key phenomena. In the eighteenth century, it was common for a natural philosopher to push illustrators to draw what their director knew to be there. In the nineteenth, for the first time, a growing number of scientists pushed themselves and their illustrators to act more like machine tenders, or even machines themselves, a living camera. It comes as something of a surprise in the twentieth century, when surgeon Ivan Baronofsky, steeped in such texts and images, proudly wrote that he had an illustrator, Daisy Stilwell, who was herself a superb interpreter. It would have been simple (Baronofsky insisted) for her merely to act as a camera, but instead she brought out the features that justified the picture. The insistence that an illustrator could productively intervene (more than a camera) is something that one would never have said in the nineteenth century; the idea being a camera or being a faithful reproducer of what you saw was paramount in mechanical objectivity. This third form of sight valued the ability not to idealize but to learn, through trained judgement, through apprenticeship, how to depict the truly important parts of an image. Judgement became part of the image.

Judgment was necessary (mid-twentieth century astronomers judged) even in regard to the depiction of the moon. When Einstein and Bohr were fighting over the nature of objectivity in quantum mechanics, Einstein pointed to the moon as an example of raw, indisputable, objective existence. The moon, he insisted to Bohr, could not cease to exist when no one was observing it. Yet when it came to looking at the craters where astronauts might land, it was very useful to have the *drawings* of a lunar cartographer named V. A. Firsoff. Firsoff argued, in an atlas of the moon, that using photographs of the moon alone would be insufficient or even dangerously misleading. Photographs, for Firsoff, had the ability to deceive; what one really needed to do was to look at so many images of the moon that an artist, through *judgement*, could correct changes of light, or reflectivity (the way shadows play at different times of day and so on), so that the operating map was the drawn one, not the photographic.

Judgement becomes explicitly a part of right depiction in the twentieth century. I have outlined three forms of sight: the ideal sight of an Albinus, Goethe or Cheselden; the mechanical objective sight of someone like Funke; and now this third form of sight in which judgement becomes paramount. By the 1960s two superb radiologists, Gerhart Schwartz and Charles Golthamer, in their radiographic atlas of the skull, argued that the natural was the enemy of the realistic. This means that if one depicted things just as they appeared, one would actually distort reality, because a critical lesion might be left invisible against the background of all that surrounded it. For Schwartz and Golthamer, judgement was needed to be realistic in the sense of correctly identifying the lesion or tumor that might actually be found on the skull. This is a complete inversion of what a mid-nineteenth-century mechanical-objective vision would have seen. Mechanical objective sight would have required: "Only depict what you see!" The whole point of mechanical objectivity was to depict things in strict and unvarying procedure, as Funke did, even including "deceptions", even when the author-artist *knew* the image seen (for example through a microscope lens) was optically distorted.

But crucially – and this is all to easy to elide – for Schwartz and Golthamer and their contemporaries (like Firsoff) using judgement was part of capturing the world in its particularity, not capturing the ideal beyond reality. Schwartz and Golthamer wanted to know about a tumor in this skull here, not about the perfect form of a tumor that nowhere actually lay dangerously embedded in a skull.

Mapping the magnetic fields of the sun, Robert Howard and his colleagues contended that if they just showed what came out of their image-making instruments, the picture would be so distorted that no one would be able to use it. So they said, perfectly explicitly that a certain "subjectivity" was needed. In other words, they insisted that only trained judgement could distinguish the artifacts from the real effects – again, not in order to idealize, but to get rid of the artifacts that were produced in the machine.

While the "truth to nature" form of sight required a sage or genius to part the curtain of particularity to see behind the image, mechanical objectivity required a scientific self that practised self-restraint. The best images for mechanical objectivity were produced not through genial intervention but through maximally automatic, protocol-driven transfer. Individuals, not universals. And then in the third category, it is the expert not the sage or worker, who produces the image of record. The expert judgement of a Firsoff, for instance, claims to be able to tell the difference between an artefact and a crater. Schwartz and Golthamer can see the difference between an artefact and a lesion, and between a lesion and a piece of normal tissue. The image is therefore interpreted *in the image itself*, these scientists used judgment to modify the images of crater, lesion and magnetic to get rid of the artifacts and to make reality visible. In trained judgment, visual depiction becomes explicitly, manifestly, one of using apprenticeship and training to exercise a new form of scientific sight.

Each of these three forms of sight gains and loses. Each filter highlights some things and obscures others. The sight-limit for judgement-based sight is that we end up not seeing at all either the idealized forms of truth that we saw with Cheselden or Albinus, or the kind of Funke-style mechanical objectivity. The well-trained image producer in judgement-based sight delivers neither the raw data of mechanical objectivity nor the maximally cooked data of the eighteenth century. This is a new form of sight, a way of gaining knowledge by ontology and by assumptions about what the basic elements of the world really were like. In this case, it is achieved through the practice of trained judgement by a particular kind of self – an expert rather than a self-restrained worker or a self-professed genius.

Those are the three forms of sight that I wanted to point to. In a next and final step, I would like to gesture toward what I consider to be a major innovation underway in scientific sight today – against the backdrop of digital imaging and crowd-sourced science. I do not want to imply that these new kinds of images are all there is, or that the older forms of sight have simply vanished. But something new is afoot, well worth our attention.

There are now digital objects that are far more vast than the kind of classic atlases I have attended to here: atlases of skulls, or atlases of blood crystals, or atlases of clouds, or atlases of hands, or atlases of skeletons. These new entities are instead huge databanks, meta-atlases as it were. They are the databanks from which atlases are themselves made. One of the most famous (the National Library of Medicine's Visible Human Project) registers the human body: one man's body and one woman's body, each digitized, forming a massive anatomical databank used all over the world. These digital compendia are taken in tiny – roughly one-to-a-few millimetre cubed – sections of the corpses. Through the use of new digital techniques, medical scientists can recode the data, travel 'through' the bodies, make tissue density show up in different colors, study individual organs, or visually isolate specific physiological systems. Doctors and physiologists can use different forms of digital intervention on the same image. They can pass through a volume of the body along different spatial axes, identify different organs, rotate them, change their color and scale, and along the way generate entirely new atlases. It represents a different relation to the image when the user, the medical scientist using it, can control it in this way.

This new, digital form of manipulation allows the user a degree and kind of intervention unimaginable in the any of the ages we have discussed (ideal, mechanical, judgmental). This very possibility raises questions of a sort we haven't yet discussed: the relation of the scientific to the aesthetic. For Albinus and his contemporaries, the idea of a radical separation between art and science would have been impossible to formulate as such: the category of "science" in a pure form did not exist. If one went back to ask Leonardo da Vinci whether or not his images of turbulent water were artistic or scientific, it is hard even to find a fifteenth- or sixteenth-century vocabulary in which to put the distinction. When the break between art and science does come to make sense is only at the time of mechanical objectivity – in the mid to late-nineteenth century, scientists were very anxious that if something seemed aesthetic, it would be indicative of a willy-nilly distortion of reality. For their part, artists were concerned about the reciprocal problem: too little intervention (as some suspected was the case in photography) seemed to indicate a lack of artistry. The hard separation of scientific images and artistic images is a mid to late-nineteenth-century creation – a division between wilful intervention and a will-less depiction.

By the 1980s, massive intervention in the images made it plausible to think about the possibility of images being *both* artistic *and* scientific. Physicists even began competing to make images that would be as much artistic as they were or aesthetic and not be in competition with being scientific. In fact, images migrated. If one had an image that was in a scientific paper, it was colored and put on the cover of *Nature*, then resized and shown in galleries as an art work among other art works. A yearly contest among fluid dynamicists looks for just this confluence: an image that is both artistically and scientifically significant.

But the digital does more than allow new forms of intervention and manipulation— the digital image can now circulate in ways unimaginable in the days of an expensive, highly produced atlas. These new and expanded avenues of travel have encouraged an expansion in the very category of the investigator. We live in an age of a growing number of "citizen scientists" who can post, interpret, and modify scientific images. In *The Galaxy*

Zoo, people from all over the world participate in the classification of images that are provided by astronomers to sort the galaxies into the different types. These hundreds of thousands of people (called "zoo keepers"), sort deep-space images both from the space telescope and from terrestrial observatories. They look for gravitational lensing, count spiral direction, distinguish galactic types where pattern recognition software as failed. At one point, speaking over the Internet to these hundred thousand or so people, one of the astrophysicists talked to the zoo keepers about a particular galaxy that the crowd was analysing, one that had been disturbed by a visible twist in its dust-lanes. One of the myriad zoo keepers responded: "Thanks Bill, it's much closer than I thought it might be, given that I believe this is one of the zoologists' discoveries."[5] The zookeeper was right and the example is not unique: astronomers have credited citizen scientists with discoveries published in a number of astrophysical papers.

An even more extreme version of this comes from the enzyme studies of a program called *Foldit* where the people studying this realized they just did not have the ability and they could not get the computer to figure out how to fold various enzymes. So they made it into a game. Players compete from all over the world to fold these proteins, e.g. a crystal structure of a monomeric retro-viral protein solved by protein-folding game players. In the competition to figure out how to fold these, they have actually solved scientific problems. This scientific image is now open to manipulation: it becomes part of an instrument, is distributed over tens or even hundreds of thousands of people, can be gamified, and all these elements combine to change the relationship that we have to an image. In *Foldit*, the citizen-scientist user is not only classifying or calling out that he or she sees something out of the ordinary; playing the game is in fact a form of interpretive, hypothesis-testing exploration. *Foldit* players, like the galaxy zookeepers, have been credited with discovery in scientific publications.

At this point, an image in this sphere is less a *re*presentation, but more a *pre*sentation. It is not as if there is an object out there that we merely are copying. In a game like *Foldit*, a distributed classificatory effort like Galaxy Zoo, or a false-color fly-through physiology of the digital man and digital woman, new knowledge can emerge. The images here are not exactly *re*productions or *re*presentation; they are more of a *pre*sentation as such. In that sense, through digital manipulation, we have created a new kind of relationship between images and ourselves, one that does not follow the sort of Kantian picture of object and representation, but rather an engineered or instrument image in which the scientific self is a combination of a scientist, a device engineer, an artist, a gamer, a citizen. The image becomes hybrid: partly simulation, intervention, mimesis, and analysis. The practice is more *pre*sentation rather than *re*presentation and the ontology is one of making things rather than finding things. It is not so much looking for whether something is natural in the creation of a nano-dot or a nano-tube, or a molecular circuit or an artificial enzyme, as if these things pre-existed us in nature and were discovered. On the contrary, it is not about discovery but about creation. In other words, the goal has shifted: this is not so much the classic epistemological question, "Does this exist?", but rather "Can we make it? Can we make it in bulk? Can we make it aesthetically, economically, engagingly? Is it acceptable to make it politically, morally?"

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5 Alison Campbell: Blog post, November 6, 2011, blog.galaxyzoo.org.

It may be that these questions begin to suggest how the near-future history of the scientific image might look. Forms of sight are always on the move.

Discussion

Eric Ellingsen: Is your book *Objectivity* itself an image of what objectivity is?

Peter Galison: An interesting question: one can ask how an image-based book might fail to capture the long and continuing history of objective depiction. First, there is a way in which the attempt to depict in a book (any book) fails. Of the things that I just spoke about there are some that clearly could not fit into a paper book. I could not have shown a "fly-through" traversing a digital body, much less the way the *Foldit* game works. There is a way in which the images that we work with now simply do not fit on the page. Or at least not on a page that is not a smart screen of some kind. Second, there is another form of objectivity that was actually anti-image: our approach to objectivity should not be by depicting things as much as they are as if in a world without us. That is not actually objective. What is actually objective would be to isolate relational structures. And that is what is real. So if you want to depict, in a simple example, the routes of the U-Bahn or the S-Bahn in Berlin, a lot of photographs could help, but it would be cluttered beyond belief. A true-scale map would clump crucial points of intersection into illegibility. And so the standard procedure has been since the late nineteenth century to make a kind of topological map that is not faithful to distances but only to the relationship between the stations, so if station two is between station one and three, really expect it to be there. But you do not think that the size, the distance between one and two and three is correctly depicted. And people think their art is a whole kind of objectivity, which Lorraine Daston and I called "structural objectivity".[6] By this, we refer to what is real in the world as objective, not the maximally faithful reproduction or mimesis of the world through the objective image. Static, mimetic images are only part of objective depiction.

In short, there are two ways in which the image in some ways starts to lose the page. One of them is when you start thinking in terms of structures. And only some of those can be made into subway maps. Or you start thinking, "well, we really need moving manipulable images that I can change, that I can alter, that I can select, or that I can change something in an image and I will alter something in a construction of a physical object in the world". Those are forms that do not fit in a classic ink and paper book. So objectivity (in its longer history) exceeds the scope of an image-based book in both ways.

E.E.: When we talk about relational images, is a system constantly an image of itself? Is any image also looking at us not just us looking at the image? Is a picture something that snaps up a system in any particular moment, while an image is something that then has to be durationally understood, something that has to engage the imagination, something that we actually then engage with to train ourselves into options of action and knowledge which does not flatten out the spatial stories or the dynamics of the

6 Ibid.

system being imaged? Are relational images implicit contracts which ask us to start to understand the constraints and the conditions that are involved in the production of any image inside that system and the terms of the systems behavior itself?

P.G.: Images exist within forms of sight as surely as poems within languages. That scientific images, too, require contextualization to be legible may be more news to philosophers and scientists than it would be to artists, because artists have the experience over hundreds of years of finding new modes of image-making that shatter prior rules of depiction. But for scientists and many scholars, I think, at first glance, they think of an image – an objective image – as being something that simply strives to be as mimetic as possible, to be a kind of copy of something out there. And what is striking when you begin to look at the history of objectivity was that that notion, that the right depiction was really just an imitation of a specific visual reality, was a very short-lived piece of the history of right depiction. It really was something that lasted (in its heyday) between, say, 1830 and 1920. Before that period, the idea of depicting things as they *looked*, in their specific and unadorned idiosyncrasy, was absurd. That is why I showed you the images by Cheselden, Albinus and Goethe. They did not want to depict this particular skeleton or that particular plant as they appeared. Though Goethe might have had a more poetic way of putting it, he thought any idiot could draw the dusty, mist-shrouded, half-eaten clover by the road just outside the post office in Jena. The idea was to show the reality that lay *behind* the appearances. And after the 1830 to 1920 period of high mechanical objectivity, people began to say, "we need judgement. If we are going to get the look of a tumor cell structure right, or correctly depict the Apollo landing zone on the Moon's Mare Tranquillitatis, or do any of the things we want to do, we do not want to idealize, we must use our trained, highly skilled judgement to be able to alter mechanically-produced images in ways that bypass accidents of observation or instrumentation – in that sense what we need are not merely copies".

The scientific image of today has become much more plastic, much more interactive, much more hybrid between simulations and mimesis, or false colours, false spatial scales and much more multi-formed than could have been imagined even thirty years ago. Our goal is to understand things, and the idea that somehow you ought to imitate, as a copy, what is out there is as absurd to scientists as it would be to an artist. A gamma-ray astronomer, a nano-engineer, a functional NMR scanner of the brain – all need a form of sight far from a simple "copy".

E.E.: When you work with someone like the artist William Kentridge, did you have to come to an understanding, a common understanding of what an image was? Or did you just work from your practices and collaborate in a way that suspended the need to agree what an image could be?

P.G.: It has been a wonderful collaboration. We met, through a mutual friend, about four years ago in New York City. Pretty soon, we discovered a mutual fascination with the aesthetics and mechanisms of the late nineteenth and early twentieth centuries. We both liked the way the inner working of things that are hidden today within black boxes were, back then, visible. Optical telescopes, and electrical machines, bell jars and wire links. Calculating machines had gears and levers, not the epoxy-sealed integrated circuits of computers today.

I had just seen William's retrospective at MoMA; he read my *book Einstein's Clocks, Poincaré's Maps*. During one of our first discussions, William said to me: "I don't want to make an illustrated science lecture. I am not interested in illustrating a bunch of scientific lessons." I said: "I completely agree, and I don't want to be a scientific consultant on an art project." Hollywood hires consultants all the time to help Jodie Foster (for example) look like a radio-astronomer in CONTACT. We got that settled: no illustrated scientific lecture, no scientific consultant. And then we began to talk, once a week in New York City and then all over the place, in Paris, Kassel, and Johannesburg. We would talk about stories or scenes; I would talk, William would sketch some things on napkins and notebooks. Early on, we began focusing on one of my favourite things for *Einstein's Clocks* – the preposterous but true circumstance that the Viennese and Parisians pumped pulses of air under the streets of these European capitals to re-set public clocks. Pumping time through pipes. What could be better than that? We began to imagine a set where huge tanks of compressed air would activate machines. More generally, we began to think about the materialization and visualization of time; machines as a stand-in for our finitude, for our terror of and fascination with mortality.

One of our most interesting discussions was about the way metaphor worked in science and art. One day, William Kentridge said to me: "Why do artists use metaphors but physicists not?" And I said: "Really? You think that? What is the most fundamental theory today? String theory! String theory wears its metaphor in its name!" There are no strings; not anything that you would recognize as such. But theorists use the notion because it points us in the direction of thinking along certain lines. One of the pervasive discussions that we had over the several years that we collaborated was: how to use the metaphorical to get at the things that interested us visually or through sound. There was a point where we were trying to think about how information could be represented. Again and again, we came back to the physics, but not in slavish illustration. Instead, we wanted to seize on moments within the history of physics where the conflicts radiated outward, metaphorically: the crushing imposition of absolute time, the loss implicit in the twin paradox, the fear behind the conflict over whether information could be lost for all time at the edge of a black hole. Or is it preserved, somehow, forever?

The structure of the piece *Refusal of Time* is in three "acts". It begins in the era of Newton and absolute time; passes through Einsteinian (relative) time and concludes as time gets distended, maybe even crushed, near a black hole. William and I talked a lot about how to think about information near a black hole; and we had some experiments that did not work. We thought that maybe we could use Morse code and encode that into the music (my bad idea). We talked with the composer Phillip Miller working with us about that and how we could make that part of the music of the piece, but eventually dropped that idea. There was a player piano in the room – I kept staring at the elaborate reading mechanism that transferred the hole-punched paper into key strikes. This was a way of encoding information – not all that dissimilar from the punch mechanism embodied in the Jacquard loom that eventually morphed into a computer. This is both historically and metaphorically a really interesting way of thinking about information. I thought this might work as a model for information flow. William then had the great idea of projecting light through the musical punch-scrolls. And in the final work we had huge projected images of the slowly falling projected "dots and dashes" that came to represent information tumbling into a black hole. In a myriad of ways over several years, we had this kind of back and forth between the literalness of machines and scientific ideas and the metaphors that, always, everywhere, surround them.

Audience-Question: I would like to ask you about the upshot of your picture for the conception of scientific change. You have these different phases and changing epistemic ideals. So, the ideal image, the mechanical image, and then something like judgment intervening. On the whole it seems to be kind of a unidirectional process with more or less neatly distinct phases, so I was wondering what kind of history is this.

P.G.: The cartoon image depicting periodization is indeed highly schematic. For each form of sight it takes us from a point in the past to the present. It is a kind of layering, almost geological – a stratum is laid down over an older one, but the older formations never disappear, they may metamorphose, but they are not evaporated. In these ways, my picture of scientific change is quite different from the picture we get (for example) from Thomas Kuhn, Paul Feyerabend, or Michel Foucault. Unlike these authors, who taught us so much in so many ways, I simply do not think that the old disappears when the new occurs. This layered periodization is therefore *not* like Foucault's epistemic break or Kuhn's scientific revolution. Specifically, the older form of sight (ideal sight) persists into our own age, as you saw for instance in the Cajal/Golgi debate in the early twentieth century. Golgi (writing in the early twentieth century, not the eighteenth) wanted to see through the image in the microscope to something else, to the reality as it must be.

What happens is actually not an absolute rupture where one form of sight disappears and another takes over, but instead the new stratum starts at a certain point; it puts the older layer under pressure but it does not eliminate it. And so you have all three forms of sight still present in the mid-twentieth century. You have ideal sight, mechanical sight, and trained or expert sight as well. But what is interesting is that under the pressure of the more recent layers the idealization changes its status somewhat. People are still interested in idealization in atlases, you can see this in biological field guides. If you go to identify a bird, people will often use a guide that's highly idealized, not photographic. What you want to know are the salient features of a bird – if there is a red spot on the bird's neck, you want to know about that and you want it exaggerated so you can recognize it. But no one thinks that the bird drawing stands for truth, no one sees a higher reality in the abstraction. Idealization persists, but what had been Platonic becomes instrumental. In these senses (layered periodization, persistence, metamorphosis), the dynamics of change are very different than the kind of gestalt-changing pictures you had in the philosophy of science back in the 1960s and 1970s.

But there is a further question that is, what drives change? Is there a single explanatory layer that makes us introduce new forms of sight? And there I am very hesitant to say that there is a single propeller that pushes us forward; that it is really "just technology", for example, or it is really "just bureaucracy", or it is really "just political". One of the things that is very striking to me is that you have something like the *camera lucida* or the *camera obscura*, which functions very differently in different epochs. Or the photograph; you might say “Well the photograph is what really … the mechanical power of the photograph makes us go into mechanical objectivity”. But actually the first thing that scientists did with photographs was to cut them up and take the best pieces of several and to assemble them into an ideal.

The instrument itself is not, therefore, determinative that way. And I would rather see the creation of new forms of sight as being the confluence of a history of objective depiction with a history of the scientific self. What, at a given time, do we want to be as scientists, the technologies, the practices, and the views about what kinds of things there are in the world? And when those combine in certain ways and they form a kind of stable and generative combination, then you have something like the rise of mechanical objectivity, or the rise of the interpretive image, or the rise of the instrument image, the kind of thing that I was speaking to in our digital present. I resist reducing the innovation of new forms of sight to a single driving source where that driver is one that has on its side the stamp of Marx or Weber or the French Revolution.

A.-Q.: On one of the last slide panels, you showed something that mentioned the change from “Does it exist?” to “Is our knowledge secure?” Is it appropriate to relate that to change in an essentialist model of knowledge versus the post-structuralist turn in knowledge? I think of *The Birth of the Clinic* and the Foucauldian distinction between archaeology and genealogy, and genealogy being more like an activist epistemology, and archaeology being more just a sort of straightforward, for lack of a better word, epistemology.

P.G.: My criticism of Foucault’s rupture periodization is specific to that aspect of his work. There is much of Foucault’s thinking – especially about a historical structuralism and about genealogy – that saturates how I think about history. In particular, Foucault, in the tradition of Nietzsche and Heidegger, is interested in making the self into a historical entity. And the self as a historical category is really the beginning point for a lot of what I am thinking about. I see not just the self in general, but a more specific notion of a scientific self, and one could contrast it and see its parallel development with the artistic self as being in some ways formed up against one another. When, in the nineteenth century, Baudelaire and other people are worried that photography, for instance, might not be countable among the arts, it’s because they think it’s not sufficiently *subject* to the will of the person doing the work. And that’s exactly the reciprocal of what the scientists are worried about. They’re worried about *restraining* the will. It’s the will to will-lessness that is the precondition for being a scientist at all in the age of mechanical objectivity – or that’s the argument that I’m making.

So, just in the measure that you can will your will away, can you become a scientist able to let nature speak by itself. But in exactly that measure, you are not doing art, according to many of the artists at that time. Artists wanted the imposition of will, at just the moment that the scientists want a will to will-lessness. They are bound against each other and each takes the contour of where the other leaves off. They define each other reciprocally, like the boundary of shore and sea. Now that division, that line of separation, that cut between art and science, does not exist before this period in the nineteenth century. It would be absurd to say about Leonardo da Vinci depicting turbulent water “This is science” – though people are forever hunting for the kernel of Leonardo’s science. Or, equally absurd, to say of Leonardo’s corpus of work: “This is pure art.” It is something else. But the line of demarcation is a nineteenth-century production. That is my argument. And it has to do with the history, and the historicity, of the artistic and the scientific selves, the formation and function of a will-based self.

So when I look at the epistemic change that accompanies the shift from “Does X exist?” to “Can we make Y, in bulk and robustly?” I am looking for a change in knowledge and in scientific selfhood. We are now beginning to see a new form of image-making, one that is not lodged in the ideal, mechanical, or judgmental. This instrument-image is something else. (You will not be surprised if I insist that the instrument image does not suddenly displace the older forms of sight, but instead builds on it, and will over time transform the older image-formations).

This older idea was that, somehow, there is a world out there, and we make copies of it. We want to make sure that our copies of it are faithful. That they fit hand-in-glove. When a Brookhaven National Laboratory bubble chamber physicist pointed in 1964 to a photograph and said: “Is our knowledge of this omega minus particle secure? Is the bubble chamber image of it reliable enough to give us confidence that we have really seen a particle that has properties that the representation indicates?” That is a classical epistemological question: How do we gain knowledge, and how do we secure it? Alongside that goes this ontological question, which is: What are the basic elements of the world that have always been there? How do we discover them? The engineer does not think that way. The gamer does not think that way. Roebling father and son, the engineers who built the Brooklyn Bridge in New York, did not worry: “Does the bridge exist?” They worried: “Is it robust? Will it carry carriages across it? Will it stand up to the tides? Will it stand up to the weather?” That is an engineering ethos. Existence isn’t the question. It is what we do with it. “How does it function? Can we make more, bigger, better?”

At the nano-scale that is often what we are doing now. Nobody worries whether there really were nano-tubes in the universe before we made them. It is not a question of any great interest to the people in a physics or chemistry or virology department now. The want to know: How do they make them? What are their properties? How do they make them reliable? How do they make that some more of them work than don’t? How do they attach them to other things? And at first, when that happened, that more engineering ethos entered into physics departments – and I remember that it was true here at Harvard and all over the world, people would say: “That’s not physics! That’s engineering.” Nobody asks that question any more. Nobody says: “That’s not physics! That’s engineering.” Half of the colleagues in my physics department here are working on problems that carry over into biology. The old field divisions, the idea that you were simply discovering things that were already existing. That you should not be making new things. That if you made new things, that made you a device engineer and not a scientist. Those sorts of divisions have really faded; we are witnessing a reformation again of the scientific self. They have not yet caught up with the classroom and our textbooks still read like something out of a previous era. But this world of making is much more where science is headed. And that perhaps addresses part of your question about essentialism. If you think of essentialism as a copy theory of the world, where the objects already exist, and our goal is to discover and secure those discoveries. If that is the older picture, I think it has begun to be challenged – or more precisely, displaced by newer concerns – in many growing areas of science.

E.E.: You are completing a movie called CONTAINMENT, which is about nuclear waste conditions around the world. One problem is using language to communicate something that has a half-life of half a million years when the last ice age was 11,000 years ago. When you are making this movie – collaborating with scientists, as a scientist, with filmmakers as a filmmaker, as someone that is affiliated with institutions – is there an image that you try to present through that project that will then go back and affect the language of the systems of the classroom, of learning, of the political and social institutions? In what way are you trying to communicate a sense of responsibility so that we can use images of speculative but inevitable futures to build up a better knowledge of now?

P.G.: Well, one of the things that appeals to me about this project and is deep in a lot of my work is I like things that are simultaneously very concrete and extremely metaphorical. And that is with partly my interest, you know, when I wrote this book about time and how time coordination began with Poincaré trying to map the world and Einstein trying to get railroads coordinated and it ended up changing the metaphysics of time. In the world today, the handling of nuclear waste is a very concrete problem. Just in the United States alone 17,000 people have been compensated by the government ten billion dollars for exposure and hurt that they suffered making nuclear weapons. And those sorts of numbers are, you know, true in the nuclear industry all over the world. Even in countries that are not making nuclear weapons, mining uranium, handling the uranium, moving the uranium, it is very concrete and how do you, where do you put this stuff when it is done? In Germany the Gorleben site has been hugely controversial for years. The other site, Asse II, is leaking, there's water in it, the government has been trying to divert the water into rivers and there have been protests about that, they don't even know that they can get the waste out of there, some of it is so badly decayed it has brought down governments in Sweden, it is a huge issue. And I spent a lot of time down in the mines with the radioactive workers; the workers handling the radioactive material in New Mexico filming and understanding what *their* concerns were. You know, they also have to earn a living, and what that meant to be a miner, what their alternatives were for work, but then at the same time, this idea of containment, of being able to secure for the 10,000 or 100,000 or 1,000,000-year future this waste becomes also very metaphorical. In fact, when the congress allowed the Department of Energy to build these mines to put the nuclear waste in, they demanded that the Department of Energy predict what the future would be like 10,000 years from now. And how 10,000 years from now people might inadvertently get into the waste. So they hired futurologists, science fiction writers, anthropologists, semioticians, artists, illustrators, a real dirty dozen of people with different skills to try to predict this. I think of this as a kind of state science fiction. They are the agency that is responsible for making nuclear weapons at the center and indeed for all the energy production in the United States in some ways, is supposed to predict a 10,000-year future and one of the people they hire is a Nebula-winning science fiction writer. And they make up these scenarios, scenarios of underground trains going from Houston to L.A. wrecking the site; of a Markuhnian conspiracy, which is a combination of

Thomas Kuhn and Herbert Marcuse that does not believe the markings because it holds that all knowledge is relative (although why you would say a Marxist would think that, I don't know). And there is even a feminist conspiracy where the feminists build a potash mine because they think that the markings must have been made by an overwhelmingly white, middle-aged population of men who wouldn't be reliable in their epistemic arguments. So they make these fantastical imaginary futures and then design monuments that are supposed to persuade people not to break in. So here you have a situation where that's the law. Predicting the future and making the future nuclear repository safe for 10,000 years is, in fact, a requirement for this multi-billion-dollar facility. So you have this combination of people who are down in the salt mine half a mile underground and this wild science fiction that then gets translated into these city-sized monuments that have to be made all the while the idea the repressed coming back out to harm us in the distant future, which gives the whole thing a kind of psycho-analytic, state-psychoanalysis structure. I find fascinating the confluence of these things in the very material reality with the phantasmagoric future. Real people being injured by real radiation set against the fantastical metaphysical ideas this brings up about time, duration, responsibility to a future that in some instances can extend into evolutionary time. Longer than people will be recognizable as people.

All this made nuclear waste sites a tremendously interesting place to dig. So to speak.