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# On Nature, its Mental Pictures and Simulatabilty: A Few Genealogical Remarks

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In a chapter titled "Scientific Imagination," Richard Feynman in his *Lectures on Physics* asked: What do I imagine when I see electromagnetic waves?

> What do *I* actually see? What are the demands of scientific imagination? Is it any different from trying to imagine that the room is full of invisible angels? No, it is not like imagining invisible angels. It requires a much higher degree of imagination to understand the electromagnetic field than to understand invisible angels. Why? Because to make invisible angels understandable, all I have to do is to alter their properties a little bit … which is … relatively easy. So you say, 'Professor, please give me an approximate description …' —I'm sorry, I can't do that for you. … When I start …, I speak of the E- and B fields and wave my arms … I see some kind of vague shadowy, wiggling lines—here and there is an E and B written on them somehow, … I have a terrible confusion between the symbols I use to describe the objects and the objects themselves. I cannot really make a picture that is even nearly like the true waves. …. Perhaps the only hope, you say, is to take a mathematical view. … From a mathematical view, there is an electric field vector and a magnetic field vector at every point in space; … there are six numbers associated with every point. Can you imagine six numbers associated with each point in space? That's too hard. Can you imagine even one number associated with every point? I cannot! I can imagine such a thing as the temperature at every point in space. That seems to be understandable.

> There is a hotness and coldness that varies from place to place. But I honestly do not understand the idea of a number at every point. (Feynman 2006, 10–20)

This is the Feynman of the early sixties, lecturing undergraduates at Caltech. We don't find a word about Bell's inequality, because these preconditions for any experimental proof of quantum entanglement were still unknown to physicists at that time. The *EPR (Einstein–Podolsky–Rosen) paradox* is mentioned explicitly by Feynman though, in the end explained in an original way by the uncertainty principle (Feynman 2006, 8–18).

But this is not the reason why I quoted this angel statement of Feynman, of wiggling in the air and seeing numbers in space. What interests me is firstly, that Feynman comes up with a question of "what is"; secondly how he thereby embraces "scientific imagination"; thirdly how he incites solving the problem; and finally how peculiar and odd he is talking about this topic.

To put it in more general terms: depicting electromagnetic waves, as this little sketch already shows, is a question of how they are rendered. And, if that is true, I would like to argue that they should be rendered as an ontological, phenomenological, symbolical, epistemological, and also an ethical or meta-ethical problem.

Ontologically one has to admit electromagnetic waves have a reality, but a very special one, possibly in the way Niels Bohr spoke about "different levels" of reality, where "conceptions like realism and idealism find no place in objective description as we have defined it" (Bohr 1958, 89).

Phenomenologically there can be no doubt: at least as much as real entities these waves are phenomena. As George Greenstein reminds us, "an electromagnetic wave is detected by monitoring its effect on charges—charges in, for instance, an antenna" (Greenstein and Zajonc 1997, 83).

Thus detected as phenomena in reality, from the outset electromagnetic waves have been shaped as symbolic mathematical descriptions rather than empirical experiences. As is well known, Feynman's six numbers at every point in space apply to Maxwell's equations which, as I will show you soon, guided Hertz's experiments to success.

On this realistic, phenomenological, and symbolic level electromagnetism has to be understood as an object and subject of a new scientific setting, opening up a new epistemology—as Karen Barad puts it, as "a nondualistic whole marking the subject-object boundary." Or with Bohr's words: different to "the scope of classical physics, where the interaction between object and apparatus can be neglected …, in quantum physics this interaction thus forms an inseparable part of the phenomenon" (Barad 2007, 136).

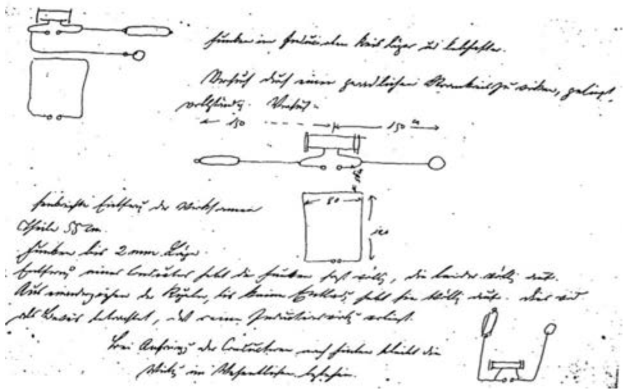
Eventually, concerns about ethics just draw the consequences of what I said about the epistemology, reality, and phenomenology of electromagnetism. As much as it comprises, on a basic quantum level, fundamental interactions between particles and wave mechanisms, electromagnetism has been responsible, over the last 120 years, for the groundbreaking successes of all new medial cultural techniques on a technological level. Electromagnetism, from the moment it came into existence as a technical phenomenon, encapsulates, in the sense of Donna Haraway, a long story in itself, still ongoing by the way, because it would never have come into existence and never would have grown to such worldwide dominance outside the subject-object connection of cultural techniques, nor outside the material, economically driven nature-culture discourses of scientific practice. According to Bohr, as Barad resumes: "The central lesson of quantum mechanics is that we are part of the nature that we seek to understand" (ibid., 265).

Not just John von Neumann's solutions of the quantum mechanical measurement problems, as I have shown elsewhere (Hagen 2002, 195–235), but already the basics of quantum theory itself have laid ground to the cybernetic feedback models in the sense of Norbert Wiener. In contrast to this, Barad emphasizes a new "ethico-onto-epistemic attention to our responsibilities not only for what we know" (Barad 2007, 283) but also, of course, for what we don't know yet.

## I.

My genealogical remarks start off with Heinrich Hertz, around Christmas Day of 1887. Experimenting in his lecture hall in Karlsruhe, its walls and ceiling luckily built purely of wood, he knew quite well that all the light falling through the windows consisted of waves as it was known since Fresnel's legendary proof of diffraction in 1819. This was already knowledge taught in schools, but any connection between light and electricity was still more than dubious. Not until 1873, just 15 years earlier, in the second volume of his *Treatise on Electricity And Magnetism,* James Clerk Maxwell had contested: "We shall have strong reasons for believing that light is an electromagnetic phenomenon" (Maxwell 1873, 383). Ten years later the two volumes were translated into German. Eventually, after one year of research, over Christmas 1887 Hertz had to fulfill this impossible Feynman task, the task that has made electromagnetic waves somehow visible and verifiable as identical with light.

I don't want to go into too much detail about why and how Hertz started off with all of this. It began, in late autumn 1886, with a famous "dipole" scenario: Hertz amplified a *Rühmkorff inductor* (a device generating continuous discharges) using two big condensers spilling out sparks, which are—this is Hertz's experimental setting—received through tiny sparks spraying off from little slits in his receiving devices of bare wire (Fig. 1).

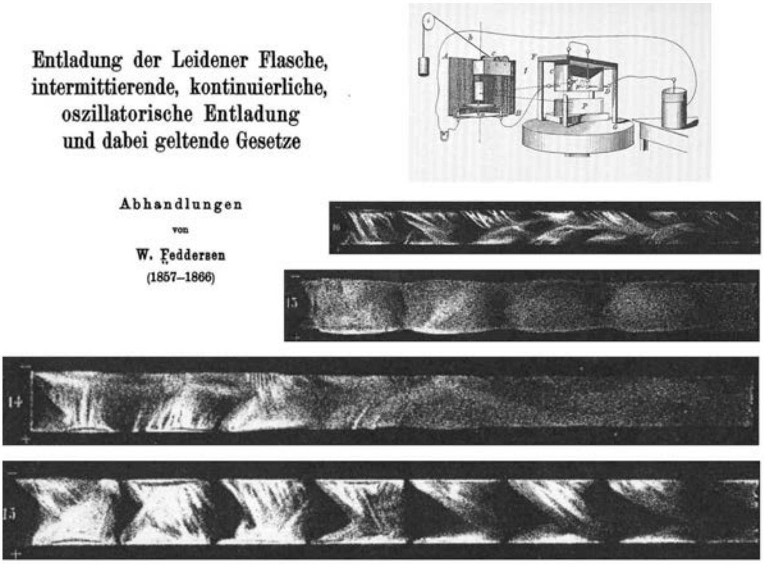


[Fig. 1] Foelsing 1997, 272

Let us remember that Hertz was part of the agent network of Hermann von Helmholtz, who held the most important post in German physics, at Berlin University, and who was very engaged in clarifying the fundamental differences between the German "nature-romantical" theory of electricity and the much more successful scientific approaches in the leading industrial nation at the time, Great Britain. To the dismay of the majority of German physicists, Helmholtz had translated Thomson and Tait's *Treatise on Natural Philosophy* as a students' textbook in 1871, explicitly lining himself up on the side of the British empirical theories against the prevailing Kantian transcendentalism in Germany. In those days Helmholtz gained the reputation of being a rude, materialistic thinker who denied the deep interconnections between the transcendental truth of nature and the human spirit, *dem menschlichen Geist* (see Cahan 1994).

As a matter of fact, one of the crucial points in this metaphysical dispute was the still open physical question of whether electricity could be a potential force with partly immediate distant effects, or if it should be conceived as a force of disturbances propagated by a so-called displacement current along conducting wires or without any carrier, traveling freely through space.

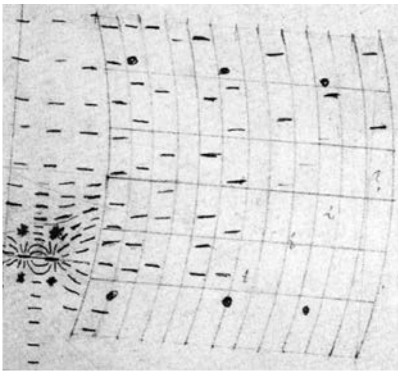
Of course, in these Christmas days, Hertz didn't see any electromagnetic waves at all. What he saw were sparks, only recognizable with special microscopic lenses, tiny little sparks oscillating in the slits of his receiver rings when he posted them on special points in his hall; luckily, as I mentioned, a room without any iron in its walls or ceiling, otherwise everything would have gone wrong, as so many failed replications of his experiments have shown painfully over the past decades (see Wittje 1995).




[Fig. 2] Feddersen 1908, Anhang I

Hertz's experimental setting was a spark-receiving circuit, extremely cute but also cumbersome. From the so-called Feddersen photo experiments of the 1850s (Feddersen 1858, 69–89) he knew a lot about the interior of discharging sparks (Fig. 2), namely that they include damped oscillations of alternating currents floating back and forth between the poles of the *Rühmkorff dipole*: "It has long been known that the discharge of a Leyden jar is not a continuous process, but that, like the striking of a clock, it consists of a large number of oscillations, of discharges in opposite senses which follow each other at exactly equal intervals." Interestingly Hertz considers this property a simulation, as he continues: electricity, to explain how it works in sparks, "is able to simulate the phenomena of elasticity" (Hertz 1896, 321).

Feddersen photos empirically affirmed the so-called Thomson formula of oscillation, $T = 2\pi\sqrt{(LC)}$,[1] and remembering that, Hertz knew roughly how fast the oscillations in his sparks were going. But, given all the elasticity, there seemed to be rather more chaotic happenings at the slit-pole of the receiving curls. Hertz knew that he could never compute the receiving spark frequencies there: their strength and brightness he could only observe with microlenses. One can imagine how tedious Hertz felt tagging specks on his floor plan (Fig. 3) where sparks looked brighter than elsewhere was.



[Fig. 3] Doncel 1995, 222

Operating with metal mirrors and huge lumps of pitch placed between the dipole and the receiving rings, Hertz proved also in principle the similarities of electromagnetism and light in reflection and refraction characteristics. In the end, after one long year of countless tests, Hertz had a few rough calculations of the possible frequencies which, divided through the velocity of light, provided him with the theoretical length of his presumed waves. But, we are in a three-dimensional room and unfortunately, even Maxwell had not really entertained calculations of free propagating "disturbances" in spherical spaces. Above all, his mathematics was all but clear to his English contemporaries, let alone to a German physicist who was trained in the differential equations of Neumann and Weber potential expressions but by no means able to work with the quaternions and pre-vector mathematics Maxwell used in his treatise. The elegance of the four Maxwell equations

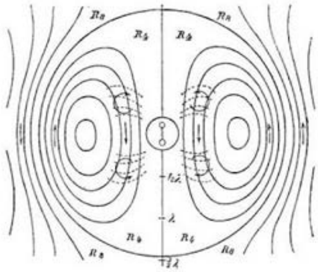
1 T = Period, L=Inductance, C=Capacity; the last two values Hertz could calculate from the parameters of his equipment.

as we know them today is in fact due to a reduction of about 12 in his book, work done by Josiah Gibbs and Oliver Heaviside after Hertz's death. However, Hertz's waves might look in 1887, elasticity simulating or not, they surely were not two-dimensional entities. So Hertz had to delve now into the very complicated mathematics of spherical harmonics in Maxwell's first volume, as his *Rühmkorff dipole* spilled out waves not in a linear plane, but rather curved in all possible directions. And above all, at a certain frequency, his waves peeled off and moved on as an autonomous electromagnetic field, or just electromagnetic wave radiation.

At the level of contemporary scientific practice, nobody could know what was really happening here. Therefore Hertz had to grapple for something intelligible that could give him a picture of what was going on, an *inneres Scheinbild (mental image)* as he would call it later on. I will come back to that later. Indeed, he pictured to himself the inner processes in the discharge sparks.

"The period of a single oscillation" Hertz wrote, "is much shorter than the total duration of the discharge, and this suggests that we might use a single oscillation as a sign" (Hertz 1896, 321). Hertz wrote this two years later, telling the story of his experiments to the German Association for the Advancement Of Natural Science and Medicine. "Taking the oscillation which he couldn't see as a sign to identify something unseeable": this sentence I would like to highlight here, because it makes clear what Hertz was really concerned with. There were not only sparks he had to receive—he had also to solve an epistemological problem. His tiny sparks didn't just receive the big sparks of the *Rühmkorff,* although these were the phenomena. But for Hertz in every spark there was something unseeable, like a furious mixture of abating frequencies caused by the damped oscillations, in every spark the *Rühmkorff* radiated. Feddersen's photos didn't show this "something" either, but gave at least a hint. Reproducing all the frequencies of a *Rühmkorff* spark on his floor-planes was impossible. Instead, here the *inneres Scheinbild comes* into its own: Hertz had to construct just one of them, one wave out of thousands the sparks radiated. He had to reconstruct one of them, estimating the length and shape of one wave, to get the points of the wave superpositions in his room (i.e., getting brighter receiving sparks to locate its shape more precisely in the room), and all this in the reality of thousands upon thousands of other waves of other frequencies swooshing around. In other words, he had to build up a precise and conscious intra-action between his apparatuses and the effects he wanted to identify.

"When you discharge the conductor of an electrical machine" says Hertz, "you excite oscillations whose period lies between a hundred-millionth and a thousand-millionth of a second … There is still the possibility of success if we can only get two or three such sharply defined signs" (ibid.). The German original is important here: *scharfe Zeichen*. Please note this unusual German expression, actually a bit unclear. What is the sharpness of a sign? Clear and distinct, yes, but sharp? Maybe Feddersen and his view about spark photographs, is reverberating here. *Scheinbilder*.



[Fig.4] Hertz 1893, 145

These now, two years later, are the harmonic spheres of Hertz (Fig. 4), very similar to what Maxwell has drawn in his *Treatise*. Seen from the strict perspective of Ernst Mach's epistemology, all Hertz had done was to make incorrect inferences. "For Mach a physical theory was no more than an abbreviated expression for a collection of statements about sense-data. Terms which could not be grounded in sensory experience were not to be retained in scientific discourse, and theories appealing to unobservable or indirectly observable entities—the electric waves of Hertz or the atoms and molecules of Boltzmann's statistical mechanics—ultimately were to be cast out as metaphysical superstitions" (Barker 1980, 247), as science historian Peter Barker put it. "Hertz on the other hand argued that … at the level of experimental observation, the correlation of sentences in the theory with phenomena in the world is [strictly and only] imposed by ourselves, …." Hertz's epistemology says that "a physical theory has a given structure is never a guarantee that reality has this structure" (ibid.).

That is to say: given the curves of Maxwell's theory, "we find as many points on the curve as we please" (Hertz 1893, 145). Let's be clear: Hertz is not faking his result. Although the curves are given here as a blueprint of his results, this is just one phase of his complex workflow. It is a phase and a part of his new intra acting approach to scientific practice.

For the last time, let's go back to the key device of Hertz and see what he has to say about how his mix of a simulative and experimental setting had worked out. "Just at the spot where we wish to detect the force" he explains,

> we place a conductor, … interrupted in the middle by a small spark-gap. The rapidly alternating force sets the electricity of [this receiving] conductor in motion and gives rise to a spark at the gap. The method had to be found by experience, for no amount of thought could well have enabled one to predict that it would work satisfactorily. For the sparks are microscopically short, … It almost seems absurd … that they should be visible. (Hertz 1896, 322)

Well, nothing is absurd here. It's a mixture between thought simulation and proof from data. Most likely, Hertz climbed on his ladder only at those spots in the room where some theoretical computation in advance had already forecasted seeable sparks. Detecting sparks in an unexpected place would mean nothing, whereas not seeing sparks in an expected spot would mean at best a failure of the apparatus. Thus, Hertz performed a growing-in-practice and self-referential intra-action between his apparatus and the theory, proving, amplifying, and giving shape to itself in a feedback loop.

## II.

Electromagnetism had to be discovered that way, or, to say it the other way round, in a Latourian turn: that's how electromagnetism produced its way of being detected. Let's keep in mind that Hertz didn't know anything about the interaction between photons and electrons: the discovery of the electron was still 10 years ahead, Planck's constant, the smallest quantum of action, 12 years, and Einstein's detection of the relativistic invariance of the electromagnetic waves another 18 years away. About 40 years ahead lay the definition of the uncertainty principle, Copenhagen complementarities, Schrödinger's equation, Dirac's *bra-kets* and von Neumann's *Hilbert space*. Nevertheless, Hertz's experimentation already shows rudimentary parts of the later quantum mechanical concept of nature. With and after Hertz nature is no longer an object of observation that remains untouched. Untouched nature, as Peter Mittelstaedt put it, is a nature "without relation to the possibility of observation" (Mittelstaedt 1986, 17 [my translation]). On the contrary, observation of nature in terms of physics is always a process of changing the observed, of constructing a new world of neo-ontological facts that are at the same time real phenomena, intelligible noumena, and subjects of empirical verification.

And, since Hertz, we have electronic media! Let's not forget, after the electromagnetic era of the telegraph, electronic media starts off with "Hertzian" waves, ironically in 1894, with Oliver Lodge's experiment in Liverpool, as a commemoration of Hertz's death. Electronic media, from radio telegraphy to the internet computer world, are based on quantum mechanically produced chips as well as on electromagnetism and the same epistemology, ontology, phenomenology, and ethics.

Regarding the medial side of his discovery, Hertz didn't anticipate it. Being asked by an engineer whether his "rays" could transmit telephone messages or something similar he replied honestly—no! Facilities for modulating electromagnetic frequencies up and down didn't exist in his time. And, he died before those weird folks like Edison and de Forest came around 15 years later, tinkering with light bulbs and cathode rays, not knowing what they were doing but thus inventing the radio tube.

Moreover, as a physicist Hertz had to cope with a far bigger dilemma. Electromagnetic waves demanded a medium for propagation, at his time called ether. His discovery seemed to affirm its existence insofar as one couldn't imagine how else these waves could propagate other than in a special medium. But, on the other hand, Hertz knew so much about the almost absurd qualities that this material should have, for example, absolute transparency for ponderable matter and at the same time an absolute density, even harder than diamond, thereby behaving totally elastically to propagate transversal waves.[2]

Hertz and Maxwell lived in the world of the ether absurdities, against which all possible inconsistencies of our quantum world look like child's play. William Thomson, the great hero of Helmholtz, had famously proposed his so-called *Vortex Atom Model* in the 1860s. While Hertz in Kiel and Karlsruhe had to teach Weber and Neumann "acting at a distance" electricity, George FitzGerald came out with his rotating model of ether molecules. After Maxwell published his theory in the 1870s, countless models came up of how electricity would travel through this rolling balls (see Nersessian 1983, 175–212). Hertz didn't live to see J. J. Thomson's electron detection and the subsequent plum pudding atom model of 1897 (see Keller 2013).

2 How familiar Hertz was with the ether theories of his time is shown in a recently found lecture from 1883: Hertz, Heinrich: Die Constitution der Materie: Eine Vorlesung über die Grundlagen der Physik aus dem Jahre 1884, Berlin: Springer, 1999.

My point is here, all these concepts, including Weber/Neumann's action at a distance electricity molecules (see Assis 1994), had one ontological assumption in common, and that is nature as a continuously comprehensive entirety, nature as an objective reality that doesn't jump. *Natura non facit saltus* had been one of the main principles of modern physics since Leibniz, who first coined this "continuity law": "c'est une de mes grandes maximes et des plus verifiées, que la nature ne fait jamais des sauts: ce que j'appelais la Loi de la Continuité" (Leibniz 1898, 110). Thus, Leibniz created a stable epistemological horizon corroborating the assumption that nature could be measurable with infinitesimal tools. More importantly, this same assumption allowed the subsequent emergence of a demand for a "completeness" of all theories dealing with a nature without jumps, called *continuity physics*. For instance, Heisenberg, still in 1955 referred to this continuity principle as if it was a cast-iron assertion. But, he gave a very "Bohrian" answer to the question of whether a quantum theory could still be considered in the realm of any continuity: "When the old adage 'Natura non facit saltus' is used as a basis for criticism of quantum theory, we can reply that certainly our knowledge can change suddenly and that this fact justifies the use of the term 'quantum jump'" (Heisenberg 1958, 9).

Long before quantum physics, Hertz took another course. After having done his heavy experimental year with electromagnetism, he started reconfiguring the relation between object and observer, subject and object, nature and culture, theory and practice. Explicitly and fraught with consequences. In the preface of his last book about mechanics we read: "We form for ourselves mental pictures [*innere Scheinbilder*] or symbols of external objects; and the form which we give them is such that the necessary consequents of the pictures in thought are always the pictures of the necessary consequents in nature of the things pictured" (Hertz 1899, 1). Again, Hertz is choosing his words very carefully; the German phrase *innere Scheinbilder* especially deserves a closer look.

Hertz follows Maxwell not only at the material level. He does it also in his epistemology, including a smart and almost inconspicuous renunciation of the continuity principle. "My theory," Maxwell had written, leads "to the conception of a medium in which the propagation takes place." We know that is the ether, never experimentally proven, but violently claimed and widely believed because of the continuity principle. "If we admit this medium as an hypothesis, I think … that we ought to endeavour to construct a mental representation of all the details of its action, and this has been my constant aim in this treatise" (Maxwell 1873, 438). How smart. Maxwell conceived electromagnetic waves as ether waves, regardless of whether ether exists. Here we already see his careful decoupling from nature as such, conceiving a new theory of nature, which leads to the concept of a "mental representation"—surely the role model for Hertz's *Scheinbild*? Even if the continuity principle had been Maxwell's guideline, the question would have to be: what is the mental representation of ether besides electricity? Maxwell's answer: I don't have one, and I don't care. By the way, this is the reason Thomson rejected the ideas of Maxwell so strenuously.

The most striking thing to be found in Hertz's sentences might be the self-referential tone of his argument. To bestow pictures with an ability—as physical concepts—that their necessary consequences should always be pictures of the necessary consequences of the natural things pictured, weaves a carpet of paradoxes that can only be resolved by the performance of a scientific practice. According to this theory, what is happening in observing nature is an intra-action of pictures with pictures, where the difference between one and the other is infected by apparatuses that encapsulate nature in a concept that Karen Barad has coined "agential realism" (Barad 2007, 165). The "certain conformity between nature and our mind" demanded by Hertz wouldn't work if nature is not part of our mind or our mind is an agent completely separated from nature. Indeed, this is a hidden variable, maybe the only necessary one in modern relativistic and quantum physics after Hertz, but if so then also, presumably, a new ethics is demanded.

"When from our accumulated previous experience," Hertz continues, "we have once succeeded in deducing pictures of the desired kind, we can then in a short time develop by means of them, as by means of models, the consequences which in the external world only arise in a comparatively long time, or as the result of our own interposition" (Hertz 1899, 1). I would like to call the reader's attention to the word *model*. What Hertz is outlining here can very well be understood as the concept of a simulation wherein we are configuring consequences that will arise in the external world independently of our ability to intervene appropriately.

In my view, the following sentence articulates the most striking and surprising thought of Hertz expressing an explicitly incomplete ontology, or to put it the other way round, an ontology of incompleteness: "The pictures which we here speak of," says Hertz, "are our conceptions of things; with the things themselves they are in conformity in one important respect, namely, in satisfying the above-mentioned requirement. For our purpose it is not necessary that they should be in conformity with the things in any other respect whatever" (ibid., 2). Let's apply this to the case of electromagnetic waves. Do we—today—know they consist of particles called photons? Yes! Does that play a role in taking them as waves as it is proven in all known diffraction and refraction experiments? No! "We do not know," says Hertz, "nor have we any means of knowing, whether our conceptions of things are in conformity with them in any other than this one fundamental respect" (ibid.). Unfairly enough, I here recall debates about complementarity as they were held decades later in the 1920s. But, from the outset, Hertz pleads explicitly for an ethic of not knowing, since we will never know what nature "in itself" would be. There is no continuity principle anymore in the world view of Hertz's scientific thinking.

"As whether only matter exists and force is a property of it," adds one of the biggest fans of Hertz, "or whether force exists independently of matter or conversely whether matter is a product of force … none of these questions are significant since all these concepts are only mental pictures whose purpose is to represent phenomena correctly" (Boltzmann 1974, 104). Again, referring to Barad's agential realism, with Ludwig Boltzmann we are in the same epistemological boat. The only existing things in nature are phenomena produced by a scientific practice led by mental pictures and symbols, but these phenomena are also enacted and acted out by nature. This is surely an idea of Bohr's, whose work is impressively resumed in the propositions of Barad, but which is also already present in the scientific thought of Boltzmann as a reader of Hertz.

The young Ludwig Wittgenstein was an intense reader of Boltzmann and thereby became acquainted with the thinking of Hertz. Wittgenstein adopts Hertz's vocabulary for his own account of the relationship between language and the world, as one reads in his *Tractatus Logico-Philosophicus*, written during the First World War:

> 2.1 We make for ourselves pictures of facts. [Wir machen uns Bilder der Tatsachen.]
>
> 2.12 A picture is a model of reality. [Das Bild ist ein Modell der Wirklichkeit.]
>
> 2.201 A picture depicts reality by representing a possibility of existence or non-existence of states of affairs. [Das Bild bildet die Wirklichkeit ab, indem es eine Möglichkeit des Bestehens und Nichtbestehens von Sachverhalten darstellt.]
>
> 2.202 A picture represents a possible situation in logical space. [Das Bild stellt eine mögliche Sachlage im logischen Raume dar.]

> 2.0212 It would then be impossible to draw up a picture of the world (true or false). [Es wäre dann unmöglich, ein Bild der Welt (wahr oder falsch) zu entwerfen.] (Wittgenstein [1922] 1984)

Wittgenstein's pioneering role in the development of analytical philosophy is undisputed and yet his so-called *metaphysical atomism* is discussed in these circles very virulently, even today. This atomism refers to the thesis that the world as a whole cannot be pictured, but all objects and things we can talk of have an enacting part in the world, otherwise they wouldn't exist at all.

And finally, Ernst Cassirer. He opened up his main work *The Philosophy of Symbolic Forms*, with a definition referring to Hertz. "The new ideal of knowledge … was brilliantly formulated by Heinrich Hertz in the introduction to his *Principles of Mechanics*. … The concept of the 'image'," writes Cassirer,

> had undergone an inner change. In place of the vague demand for a similarity of content between image and thing, we now find expressed a highly complex logical relation, a general intellectual condition …. Its value lies not in the mirroring of a given existence, but in what it accomplishes as an instrument of knowledge. (Cassirer 1955, 75)

Last comment: with and after Maxwell and Hertz, electricity gained a powerful epistemological dimension, but thereby it lost its *Anschaulichkeit*, its clarity, its aesthetic dimension completely. No similarity between image and thing anymore, to say it in Cassirer's words. Today, a silicon chip, as the most important piece of electricity, is an entirely anesthetic and "anesthesial" (see Derrida and Kamuf 2014, 26) device in the sense of Derrida's use of the word. In silicon grids we distinguish electrons from holes, as Shockley told us,[3] although electrical holes have no existence physically. On the other hand, without it, without these "holes", nothing would work in any modern computer, although there is no such a thing as a hole. Nobody will ever "see" it. It has, if at all, a quantum mechanical meaning only. Do these holes represent the magic of modernity, whose aesthetic potential holds the promise of a reconciliation of man and nature? I doubt it. The same applies to the electrodynamical occurrences in an antenna, the interchange between electrons and photons generating one of these myriad of

3 William Shockley was one of the inventors of the transistor in 1948 and the creator of its theoretical description, *Electrons and Holes in Semiconductors: With Applications to Transistor Electronics*, New York: Van Nostrand 1950, IX: "The hole, or deficit produced by removing an electron from the valence-bond structure of a crystal, is the chief reason for the existence of this book."

electromagnetic waves that hold our world together—does anybody feel the magic of reconciliation here? I'm not sure. Starting with Hertz, we live, as Barad puts it, maybe for a century now, in "agential realities." But instead of reflecting, in plain language, their limits and obligations, we still dream of them as a universal nature where electrical sparks spraying out of our head would tell of our vivid soul. But that's not the world we live in anymore.

That brings me to the famous Einstein, Podolsky, and Rosen article of 1935 concerning the problem of quantum entanglement. "Any serious consideration of a physical theory," Einstein and his colleagues wrote, "must take into account the distinction between the objective reality, which is independent of any theory, and the physical concepts with which the theory operates. These concepts are intended to correspond with the objective reality, and by means of these concepts we picture this reality to ourselves" (Einstein, Podolsky, and Rosen 1935, 777). So far, this refers to the Hertzian lemma of 1894, but interestingly Einstein continues differently. "In attempting to judge the success of a physical theory we may ask ourselves two questions: (1) 'Is the theory correct?' and (2) 'Is the description given by the theory complete?'."

As we have seen, completeness is what Hertz and Boltzmann somewhat excluded from their theory, and it might have been one of their crucial arguments to get rid of continuity physics and its epitomes like ether. Maybe Einstein's recollection has an inkling of that, so he feels he should become more verbose now: "Whatever the meaning is assigned to the term complete, the following requirement for a complete theory seems to be a necessary one: every element of the physical reality must have a counterpart in the physical theory."

I would like to sum up my genealogical review of Hertz by noting that Einstein, in his objection to quantum entanglements, re-established the horizon of continuity physics explicitly. But this quantum discourse emerged from the same scientific work that Einstein owed his early theories to—and this work was forced to get rid of all continuity prescriptions epistemologically. Maybe Hertz did that for the sake of a better world? We don't know.

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## Discussion with Wolfgang Hagen

Hans Jörg Rheinberger: Thank you very much for this fascinating historical path that you have made us follow. When I looked at the translation of "innere Scheinbilder," I found it particularly stupid to call them mental pictures. Why didn't you translate it as internal simulacra?

Wolfgang Hagen: I take the translations published wherever possible, so I don't have to correct them so much.

HJR: And then the other point is with respect to the introduction to this—to Hertz's textbook—I think talking about these "innere Scheinbilder" and taking them as signs, that's all plain Helmholtz in a way? That's Helmholtz's sign theory applied to the particular purposes that Hertz has in mind there, but he is, if I remember correctly—it's a long time I've read this introduction—also making the claim that there is not just one consistent set of "innere Scheinbilder": you can have many of them that can be taken as being equivalent to each other.

WH: It's not explicitly stated in the preface; maybe he worked on this later, I don't know.

Eric Winsberg: So what's the German word for...

WH: "Innere Scheinbilder"

EW: I thought "Gedankenbilder" was the mental picture?

WH: It's not "Gedankenbilder," it's just "innere Scheinbilder." Here we have the slide. Some translations used mental images and some used symbols. I'll show you the real source of it—it's Goethe actually, I found out. It's from *Theory of Colors*, obviously.

"I looked on the bright circle five seconds and then having closed the aperture saw the colored visionary circle floating before me." And the colored visionary circle, this is an English translation of Goethe, is in German "das farbige Scheinbild." It's actually what you discover when you look too long into a very bright light and then close your eyes and then you have this...

EW: And that's the expression Hertz uses?

WH: Yes, "Scheinbild," which is untranslatable into English because it's not an illusionary picture, it's wrong. "Scheinbild," it's a Goethe word, that's all.

EW: It's what we call an aftereffect in English?

WH: Yes, but it's not an aftereffect because it's Goethe's theory of colors. It's very romantic.

Anne Dippel: The first time this "Scheinbild" appears is in Plato's cave.

WH: But not in German.

AD: No, but it would be helpful to look up the Greek word…

WH: Very!

AD: …and then from the Greek word you could come to the…

WH: Goethe.

EW: You have to translate it into "Scheinbilder" okay, from the…

AD: No.

EW: If you translate it from Plato it would be "Scheinbilder."

WH: The word is seldom used in German. So I looked it up with every tool I have, in all the digital libraries, and I only found this Goethe quotation, which is cited very often in many other books.

AD: I'm sure you could find it in Hermann Pauli's Etymological Dictionary or in Kluger or in Grimm. I am very, very sure that…

WH: Yes, of course.

AD: … this word is described etymologically and then you find the first time it appeared. But double terms in German appear from the sixteenth century onwards, so it is a new term, it must appear around 1870.

WH: Interesting, that's a good explanation. It's a very interesting word, because it's so important.

Lukas Mairhofer: So since you betrayed us, I of course have to ask about Wittgenstein, and also because when you ended with Einstein I thought, well, where is it that this continuum physics comes in again on a more epistemological level? Is it maybe with Ernst Mach? Is that maybe one of the big frictions between Machian thought and the Boltzmann–Hertz approach?

WH: I don't know, actually. I can't answer the question because I would say that the prominence and the popularity of Wittgenstein and Cassirer—and their relation and reference to Hertz, making him prominent as well—is very important in this context. So Einstein for sure knew Wittgenstein and the Frege group and all that, maybe he knew Mach better. I don't know. But either way, the original Hertz was not read and the original theory of Boltzmann referring to Hertz was not known anymore.

The whole "Scheinbild-Theorie" was kind of thought of in the context of Wittgenstein and Cassirer, as it is today. But the most important point for me is not the "Scheinbild-Theorie" but the break with continuity physics.

John Durham Peters: So, okay, I'm not a physicist, I'm a media theorist…

WH: …like me.

JDP: …and it strikes me that what you found is ground zero of media theory, in which all the contradictory notions of media are actually combined in Hertz…

WH: …that's right.

JDP: …whereas before you've got the kind of natural element, like the ether, after the mass medium of radio, you're talking about the variety of semiotic practices by which we reveal reality. But I think the one you're most interested in is the fact that the medium is something in which we intervene and thereby represent at the same time.

WH: Right.

JDP: And so I guess my question is: what is a medium? And that'll be the question for the previous lecture as well. I'm still confused by this question.

WH: But you gave the answer. I mean Hertz's reflection on what he did is in a way media theoretical as well, of course. So you're completely right. And we have—I've argued in this direction for a long time already—that media theory, which doesn't exist: media epistemology is equivalent to quantum epistemology and even cybernetic epistemology, because the figure of feedback mechanism and the figure of the self-referential building of not only concepts but the interaction between apparatus and nature, which is conceived in cybernetics as well, obviously stems from this source.

Arianna Borelli: I usually try to avoid using the term media too much. I know enough of media theory to know that there are all new media. In this context and sometimes when I present this subject, I like to use this term medium, as you would say, to prompt thoughts to go in a direction different than if I would say representation or form, especially if I'm speaking to historians of science or philosophers, to point out that there is some dynamic there in this representation, it's not passive.

Martin Warnke: Well friends, thank you so much. Now having brought us to the point where we just don't know anymore about the difference between theory and simulation, would you still make any difference after, say, having given up the continuity hypothesis?

WH: No, epistemologically not, but maybe in a way Eric showed us yesterday, practically. Because simulation is a new field of symbolic practice, maybe algorithm practice, I don't know. It has to be defined as a new field of practice, and epistemologically it's equivalent to any mathematical theory of nature. But that is not enough of an answer for what is a good simulation. We have to think about a kind of taxonomy of simulations; I don't know. I was not giving a lecture about simulations, but there must be a kind of taxonomy or something, a kind of logical work on it; the epistemological question you asked me—I mean, this seems for me to be answered.

It's like Hertz says, I mean it's elasticity, it's simulating elasticity.

Frank Pasemann: Yes, I'm a little bit confused by the concept of simulation. Of course I would like to discern between simulation in the sense that you can simulate something in the world in your brain, from computer simulation, which is of course perhaps closer to the media thing. So one should keep these as different things, at least for me.

WH: Of course.

FP: Otherwise there is a lot of confusion.

WH: What would you say about quantum simulation in the sense of Feynman, done without computers? Done without tool machines?

FP: I mean it's just to be precise what you mean by that.

WH: That's what I say…

FP: Otherwise we get confused.

WH: We have to have a kind of taxonomy.

HJR: Right. Exactly, thanks.

EW: Just a quick comment about the EPR quote that you put up: my memory of this is a little bit murky, but I think I remember Arthur Fine (2016) saying that that particular passage about elements of physical reality was one that Einstein didn't approve of, it was Rosen's—he wrote that passage I think and it might have been added to the draft after Einstein had seen it, before it went to press.

WH: Really? Okay.

EW: He might not have been a big fan of that.

WH: I mean god is not dicing, right?

EW: What's that?

WH: God is not dicing.

EW: Yeah, yeah.

WH: Playing with dice, so it's a continuity statement as well.

HJR: So absolutely, an atomistic statement. Very strange.

AD: I have two questions: I would love to hear something about that ethical dimension; and the second, it is very, very interesting what you said about the meaning of the image and the "Scheinbild" in mind and nature and so on. But when you look at actual physics practice, not in quantum mechanics, but in other fields, like high energy physics, the image itself is not important anymore as a device inside nature.

WH: But the simulation is important.

AD: The simulation is important.

WH: This is the image part.

AD: So you would just translate the digits and the algorithms and say that's equal to images?

WH: Of course.

AD: …and there's no distinction between the algorithmic image and the visual image, because it seems to me there is a big distinction and that humans make sense out of that, and it's easier for us to somehow interpret images compared to letting the machine do the work, the medium doing the work of interpretation.

WH: That's right but we program the machine, as long as we are dealing with Turing machines, so there is the image part in it for me. Creating an algorithm is a way of creating images, so to say, because what is an image, on the other hand? What is a picture, on the other hand? Actually we don't know.

AD: Okay, got that. The second thing is you mentioned those examples from the natural sciences in the nineteenth century where the idea of a continuous or unified worldview somehow breaks apart, and that is something we observe not only in physics but we observe it in many, many other domains, in philosophy and so on. And then you show us how this need for some homogeneous description of the world returns through this. What kind of symptom is that? Wasn't it a liberating situation that Hertz detected, and how do you describe this constant urge and need of people to find some unified theory, when the world isn't unifiable according to what Hertz stated from logical reasoning?

WH: I don't know. I mean: have a guess! Maybe there are political reasons, or maybe economical reasons, to have a separate realm of nature only physicists can work on. I mean I don't know what the reason is to come back to continuity, to the physics of continuity or to a nature that is an entirety.

AD: Well, that was a power practice then in the end.

WH: Power, power may be one—maybe some other—I don't know, I mean I have to think about that, like you. But what I can say is that Hertz took another course and then he died, so to say. I mean that maybe electromagnetism as he found it took another course. I would just emphasize this Latourian picture of his experiments. You can say electromagnetism demanded this way of being detected. Know what I mean?

And this is a way we should think in the future, and therefore Karen Barad's approach is so interesting because she, in my view, is one of the first who radically thinks in a way that quantum physics and classic physics are not the problem, but the nature–culture relation in physics in general. So we have to think about that again under this perspective and from the start of the history of electromagnetism. Because for me electromagnetism makes a great cut into history. This is a real epoch break so to say.

There, in 1888, begins modernity, and not earlier, because electromagnetism is the first force, power, whatever, medium, we can produce in interaction with nature, so to say. It changed everything. I mean, just on a simple historical level you can see that. The industrial success and everything of the western world depended on electromagnetic techniques. And that's my point. We have to reconsider that under this epistemological horizon Hertz gives us. We have to really dig in under this horizon, and then we come to the point of ethics. Because there is a hidden variable, as I put it, between nature and mind, and there obviously is one, because there has to be a conformity, as Hertz says. Neumann would have described it—in his measurement chapter, which is very interesting—as an exchange of entropy and knowledge. That's his argument. In his measurement chapter, he says we can exchange entropy against knowledge. It's a very interesting thing. It stems from Fechner and this physio-psychological view of the world and things like that. Nobody invented something by himself. So, what I want to say is, this is kind of a part of physical thinking we should go back to, to discuss our problem of simulation of nature.

MW: What came back to my mind was that paper by Kittler (1991), where he says that computer simulations jump over the category and the register of imagination. I don't know what your opinion on this is. Then, we would have a difference between "innere Scheinbilder," because there are no "innere Scheinbilder" anymore, according to Kittler, if we would believe him. Because he says this is exactly the very nature of computer simulations, that there are no inner pictures anymore, this register is jumped over and left out. Would you think this argument has some reason to it?

WH: I wouldn't agree with your statement.

[To Kristel Michielsen and Hans De Raedt] I'm very interested in the source code of your simulation. Because I programmed for maybe 7–8 years in a row for other reasons, and the subjective experience I had was that programming is working with "innere Scheinbilder": you can't create an algorithm without having the imagination to think about how the machine works. So, what else is it than an "inneres Scheinbild"? Because it doesn't exist. The computer you're thinking about—wired programming—doesn't exist. And that's a problem all the time, but you know what I mean. So, the performance of programming is exactly creating "innere Scheinbilder" in a mathematical and special structure. And, whoever did that, seriously, will agree. Right?

HJR: But I think the really interesting feature of this paradoxical formulation of "Scheinbild" is that it is deconstructive.

WH: Yes, right.

HJR: On the one hand, it says picture; on the other hand, it denies…

WH: It says “Schein.” Yes, it’s wonderful. Good remark.

Hans De Raedt: I fully agree with what you said about, say, the practice of computer programming and so on. But, maybe I would also like to make a bridge to what Martin says because, when we have done this… I’m talking about computing on a digital computer, we know that, at least in principle—but we can also do it in practice, although it is fairly expensive—we can build a, let’s say, Lego machine that does exactly the same thing that our program is doing. So then, would you still call that a “Scheinbild”? So I have now a mechanical…

WH: That’s an interesting question.

HDR: …device that is doing exactly the same type of thing. I mean, not exactly in terms of, say, basic things it does. But the final result is the same—things are moving around and so on. So it’s really mechanical. We can clearly visualize it. I mean, it’s a natural thing for us, and it does the same thing. So where are the “Scheinbilder” then?

WH: I thought about this tinkering. I mentioned Edison and de Forest, successfully, because they are building the radio tubes, which are so, so immensely important for the evolution of electromagnetic media. But neither Edison nor de Forest knew a thing. Maybe they worked with “innere Scheinbilder,” I don’t know. But, the main thing is, they worked with material. They did it. They did it somehow. They tinkered, they just practiced by playing around with things. This is not “innere Scheinbild.” When I programmed, I couldn’t play around with things. I would have liked to do that, but what I played around with was some things in my head, and I can’t even describe them.

FP: And just as a comment I spontaneously would think the same thing. But when I talked yesterday about the explorative simulations, you can think about programming, creating new programs, and constructing systems you haven’t thought about. And that’s one of the interesting things today.

Britta Schinzel: To add to the “innere Scheinbilder” effect from logic recursion theory: we know that for every mathematical function, there exists an uncountably infinite set of infinite sequences of equivalent programs. So, you know that every “innere Scheinbild” produces a different program, a different source code.

HJR: Now things are starting to become messy and complicated at this point. Let us stop here, and thank our speaker for this stimulating discussion. Thank you.

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