Helmholtz' Apparatuses
Telegraphy as Working Model of Nerve Physiology

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Introduction

In Hermann von Helmholtz' physiological writings the word 'apparatus' can have several meanings. In his famous treatise *Die Lehre von den Tonempfindungen als physiologische Grundlage für die Theorie der Musik* (1863), for example, Helmholtz refers to at least three different apparatuses: the experimental "apparatus" used for producing single tones, the "apparatus belonging to the drum of the ear", which consists of hammer, anvil, and stirrup connecting eardrum and labyrinth and, some pages later, the "termination of the auditory nerves" in Corti's organ is characterized as a kind of "peculiar auxiliary apparatus" made for resonating [Helmholtz 1870, 178, 199, and 212]. The diverse use of the word was by no means unusual in the golden age of German 'organic physics' in the decades between 1845 and 1870 [Lenoir 1997, 75-95]. On the contrary the ubiquitous talk about apparatuses itself might be understood to constitute organic entities as physically defined technological objects. As a consequence it could appear that it is only meant metaphorically, when Helmholtz talks about the several parts of the inner ear in terms of an apparatus. But if we understand metaphors with

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Hans Blumenberg mainly as "fossils that indicate an archaic stratum of the trial of theoretical curiosity" [Blumenberg 1979b, 82], then the perspective shifts and what appears as an explanatory principle introduced ex post, turns out to be a remnant or sediment of the research process itself. In fact, since Xavier Bichat's *Anatomie générale* (1801) physiologists of the 19^{th} Century not only distinguished some organic entities from others *as* apparatuses [Bichat 1801, I, XCIX]. First and foremost they investigated and determined characteristics of organic functions by means of apparatuses.

With respect to Helmholtz' work on the qualities of tone Timothy Lenoir has shown, how in the course of experiments telegraphic devices, sound forks and resonators were arranged as a "material model of the ear in reverse" [Lenoir 1994, 204]. What happened here and in a number of other physiological investigations of the period was that apparatuses or parts of them not only helped to carry out experiments and observations. They were simultaneously perceived as representations or models of the research object itself. As Lenoir suggests, the experimental set-up Helmholtz used in his investigations did not simply allow him to arrange such a problematic research object as the qualities of tone. Within this set-up the process of sensation and the function of the ear in general became understandable in a new way: "The representation thus fundamentally affected the articulation of theory." [Lenoir 1994, 206].

Referring to scientific apparatuses and experimental set-ups as models implies a substantial change of their status within observations and experiments. As Hans-Jörg Rheinberger has suggested, scientific problems and experimental conditions or, in his terms, "epistemic things" and "technical objects", are "engaged in a nontrivial interplay": "The technical conditions determine the realm of possible representations of an epistemic thing; and sufficiently stabilized epistemic things turn into the technical repertoire of the experimental arrangement." [Rheinberger 1997, 29]. Accordingly one may invert Gaston Bachelard's often quoted dictum that „instruments are nothing but theories materialized“[Bachelard 1934, 13], and say that materialities leave their mark on the interpretations of epistemic things. But Lenoir's concept of experimental apparatuses and technical devices as material representations or models of physiological processes calls for further refinement. In his example the arrangement of apparatuses works as model in two ways: as a hypothesis of the inner ear's functioning and as a schematic but on principle exact reproduction of the organ's properties. In general, however, it seems that a certain apparatus must neither be actually present in an investigation in order to have an effect on the latter nor can the relation between the model-apparatus and the modeled object be reduced to one singular possibility. This is in particular true for the several attempts to develop the nerve's qualities with respect to the telegraph wire. As a closer look to the German speaking context between 1810 and 1860 will show, telegraphic installations attracted rather different problems of nerve-physiology at different times.[1]

Discussion

The years around 1800 mark the beginning of a new epoch in the history of telecommunications. Had telegraphy previously been the toy of amateurs and outsiders, it came under the protection of the state at the turn of the Century, when large optical telegraph-lines were built and plans for electrical telegraphy were developed [Aschoff 1989, chap. 9-11]. These decades are also regarded as a time of a major change in the history of physiology. The Cartesian, mechanically determined "homme machine" made way for the new "homme sensible", characterized by an excitability and sensitivity of a still unknown nature [Moravia 1978]. Both the development of telegraphy and the conceptualization of the human body as a sensorimotor organism touch on the same problem of information-transmission and -exchange. Practical questions are: by which force can a sign or a sequence of signs be transmitted over longer distances, what kind of principle guarantees that a sensation from the periphery of the body arrives without damage in the 'sensorium commune', what induces the voluntary movement of a muscle and in which way can information — a word or a sentence — be represented in signs. Around these problems manifold points of contact evolved between telegraphy and physiology in the course of the 19^{th} Century but, as we will soon see, apparatus and organism did not form a stable, continuous relation

It seems to be a conventional analogy, when, in the 1860's, Helmholtz pictures the nervous system, the sensory organs and the muscle activity as a system of telegraphic wires, transmitters and receivers at length towards the end of his argument on the perception of the quality of tone. At least this impression is aroused in his first sentence: "Nerves have been often and not unsuitably compared to telegraph wires." [Helmholtz 1870, 224]. It will become clear shortly, what "often" really means. Helmholtz himself may have had a popular lecture given in December 1850 in mind, were he drew this parallel for the first time [Helmholtz 1882-1895, II,

[1]For the widespread (not only physiological) contexts, in which after 1850 the human organism became related to communication devices, see [Otis 2001].

873]. Some weeks later and independently from Helmholtz the physiologist Emil du Bois-Reymond developed the same idea in a lecture on 'animal locomotion' [du Bois Reymond 1912, I, 47-48]. Despite this chronology, Helmholtz acknowledged his colleague's original authorship: "With regard to the correspondences in our lectures, I leave the priority of the electric telegraphs to you because I heard the hypothesis that the ganglia represent the relays of electric telegraphs in the nerve-lines from you a long time ago." [Kirsten 1986, 111]

What apparently neither Helmholtz nor du Bois-Reymond remembered, was the simple fact that Johannes Müller — their mutual teacher at the University of Berlin — had already compared nerve fibers to "conducting wires covered with silk" (although not explicitly to telegraph wires) fifteen years earlier in his fundamental *Handbuch der Physiologie des Menschen* [Müller 1833-38, I, 684]. Müller himself refers to a publication by the physicist Gustav Theodor Fechner and, as we will see, Fechner in turn silently picked up an idea of the famous anatomist Samuel Thomas Soemmerring. Without doubt one can easily assume more complete and above all other genealogies beyond the German speaking scientific community. But what matters here is that the history of the comparison between nerve and telegraph wire in itself shows such a forgetfulness that questions of priority and a perspective, which seeks for a constant relation, become futile. If, in the following, Soemmerring forms the starting point of my analysis, this is not because everything Helmholtz or du Bois-Reymond, for example, thought and wrote on the relationship between the physiology of the nerve and telegraphy originates from here. It rather marks an early attempt to connect these areas, which was subsequently transformed and partly abandoned.

In his treatise "Über einen elektrischen Telegraphen", published in 1811, Samuel Thomas Soemmerring gave an account of the galvanic-electric telegraphic apparatus he had constructed in the years before on behalf of the Bavarian Academy of Science.[2] As source of electricity for the transmitter he used a voltaic pile, to which 35 wires could be connected, each of them representing one of the 25 letters of the German alphabet and the numbers 0-9 (Fig. 1)[3]. The receiver consisted of a container filled with water where every single wire coming from the transmitter ended separately. In order to transmit a message, two of the wires were attached to the negative and the positive pole of the pile, thus closing the electric circuit. As a result, hydrogen respectively oxygen was set free in the water container at the ends of the two wires. Thus two let-

[2] For the history of Soemmerring's enterprise see [Wenzel 1993].

[3] Figures are to be found at the end of the article, p.147.

ters or numbers were telegraphed [Soemmerring 1993]. Concerning the arrangement of wires between transmitter and receiver, Soemmerring remarked:

> It is admirable, how 35 segregated effects of electricity occur through such a rope without considerable disturbance!
>
> Indeed! How much does not such a rope stimulate reflections even of a physiologist, when he becomes aware of it as a rough sensorial analogy of a nerve cord, whose single fibers propagate every received impression of a sensation in general and the smallest electric spark in particular insulated and undisturbed to the brain in the same manner. [Soemmerring 1993, 134]

This idea was certainly remarkable. But there is little reason for the occasionally raised assumption that Soemmerring modeled his electric telegraph according to ideas on the representation of sensations in the brain developed by Immanuel Kant in his epilogue to Soemmerring's treatise "Über das Organ der Seele" [Siegert 1997, 94]. In fact, for constructing the apparatus he had no need to consult any of his writings — neither the speculative nor the sober scientific ones.

In terms of the patent law the inventive step of Soemmerring's apparatus was rather low. Nearly every proposal for electric telegraphy around 1800 relied on the idea that for the transmission of each letter or signal a single wire should be used [Aschoff 1989, 119-138]; in particular those, which Soemmerring annotated in his treatise.[4] His own contribution to telegraphy lay mainly in his combination of established concepts with the technology of his time: instead of using Leyden jars as source of electricity and sparks, frogs, bells or hands as receivers, he used the galvanic battery and the electric decomposition of water, both discovered and developed in the last years of the 18^{th} Century, as telegraphic devices for the first time. Only the "insulation of every single wire" [Soemmerring 1993, 134], which allowed tying them together, was entirely new. According to Soemmerring's treatise, complete insulation can be attained "by wrapping round [the wire] with silk". However, the use of sealing wax for insulation is also mentioned at an earlier stage in his experimental diary (Fig. 2) [Soemmerring 1786-1823, 89]. Regardless of the solution finally selected, it was exactly this detail of Soemmerring's construction, which connected his work on the telegraph with a problem both virulent and obscure of nerve-physiology.

[4] In a footnote to his treatise Soemmerring refers to the telegraphic devices of Reußer (Soemmerring: Reiser) and Salvá y Campillo, which both comply with the model 'one letter — one wire' [Soemmerring 1993, 125-26].

Around 1800 it is hardly more than a hypothesis that each "impression of a sensation" is propagated "insulated and undisturbed to the brain" by a single nerve fiber, as Soemmerring claimed alluding to the cable of his telegraph. In the second edition of Friedrich Hildebrandt's widespread *Lehrbuch der Anatomie des Menschen*, there is merely a remark that this opinion was "plausible" because, as the author added in a note, "the soul (in the brain) distinguishes between sensations from *individual* parts of the body and can act on every *single* muscle separately." [Hildebrandt 1798-1800, IV, 373]. One year later, in his "Hirn- und Nervenlehre", Soemmerring also noted that the single nerve fibers "originate from the brain or the spinal cord" [Soemmerring 1800, 114]. Unlike Hildebrandt, however, he believed less in logical conclusions, than in empirical data and therefore had to confess, "that it is not at all easy to identify a single fiber." [Soemmerring 1800, 108]

Since Felice Fontana published his note on the so called single nerve cylinder or single nerve fiber in 1781, every comment on the subject of the single fiber was based on highly speculative microscopic observations at the limit of the lens-systems available in those days. In order to overcome remaining doubts at least apparently, Fontana himself had "recourse to a very strong lens, which increased 700 times the diameter"[Fontana 1781, II, 236]. Nevertheless, the number "of transparent, homogeneous, uniform, very simple cylinders"[Fontana 1781, II, 238], which, according to Fontana, every nerve consisted of, did not at all look like the wires of Soemmerring's telegraph (Fig. 3). But the comparison between nerve fiber and single wire did not postulate a morphological similarity; instead it freed speculations on the possibility of a continuous nerve connection from the status of precarious microscopic observation. Not without reason did Fontana publish a short essay on "Erreurs Microscopiques" in the same volume, in which he announced the discovery of the simple nerve cylinders, concluding that "of all microscopical observations, I know of no one that can easier lead the most consummate and penetrating observer into an errour, than the external structure of the nerves" [Fontana, 1781, II, 287]. Soemmerring himself was skeptical of Fontana's description and in the first edition of his "Hirn- und Nervenlehre" (1791) he explicitly rejected the nerve cylinder-hypothesis without abandoning the idea of a continuous single nerve fiber [Dougherty 1985]. In this respect, his telegraphic apparatus did not serve as empirical proof for a certain anatomical doctrine. Instead, Soemmerring discovered it mainly as an easy usable set-up, which proved that the transmission of single elementary sensations was possible at least materially. According to Dominique Jean Larrey — leading surgeon of the 'grande-armée' and propagandist of Soemmerring's telegraph at Napoleon's court — what became visible was a „simulacrum nervorum" [Larrey 1810, 221].[5]

Fontana's observations and the hypothesis of a single continuous nerve fiber were amply criticized in the subsequent decades, but this did not bring to an end the telegraphic modeling of nervous processes. The next researcher to come back to it was Gustav Theodor Fechner in his *Lehrbuch des Galvanismus* (1829), which formed part of the German edition of Jean-Baptiste Biot's *Précis élémentaire de physique expérimentale*. Here, like many of his contemporaries, Fechner claimed that every nervous activity "is simply an electric fluid". This doctrine was very widespread since the early 1790's, when Luigi Galvani postulated that nerve and muscle could be understood in analogy to a Leyden jar and its conductor, and it was no less debated, than the idea of the single nerve fiber. As is well known, Alessandro Volta and his supporters rejected Galvani's idea of "animal electricity" successfully,[6] but the very idea of the electric nature of the nervous processes did not vanish. Fechner claimed accordingly that the function of the "whole nervous system" seems similar to that of a "closed galvanic apparatus" — an electric circuit between the negative and positive electric pole of a galvanic pile — in which "only those parts connected to the circle, can perceive its effects." [Fechner1829, 505] Disputing the argument that in this case the nervous activity would disperse arbitrarily in the stimulated nerve and from nerve to nerve he continued:

> These objections disregard the possible insulating quality of the nerve's *coats*. What is actually conductive in the nerves is only the *medulla* and every nerve can, to a certain extent, be considered as a bundle of wires lying side by side and wrapped in silk. [Fechner 1829, 508]

Obviously Fechner is referring here to Soemmerring's reflections made twenty years earlier, although he spares himself the footnote. But for Fechner the model of the wire did not embody a certain concept of the anatomical characteristics of the nervous system. Instead it proved mainly that a certain nervous principle — namely electric processes — was feasible. Unfortunately, the physicist Fechner, who became famous as the founder of Psychophysics in the 1860's, did not know much about

[5]Larrey visited Soemmerring in Munich in November 1809 and presented the apparatus one month later in Paris to Napoleon. Soemmerring had already mentioned the comparison between nerve fiber and telegraph wire in a manual written for this demonstration, dated „5 Novembre 1809" [Soemmerring 1809, 9]

[6]For a critical account of the debate between Galvani and Volta see [Pera 1986].

the physiology of the nerve. Some years later Johannes Müller easily rejected Fechner's claim, indicating that "the neurilema [the nerve's coat] itself is an excellent conductor of the galvanic fluid, and the nerves, [...], have not a greater conducting power than other moist animal textures." [Müller 1833-38, I, 684]

When Helmholtz, in the year 1850, related the nerve fiber "not unsuitably" to the telegraph wire for the first time, he once again had a very different interest from his predecessors Fechner and Soemmerring. For him, "the rapid conduction", which, according to Fechner, was characteristic of both the "nerve fluidum and the electric fluidum" [Fechner 1829, 509], became the central problem: "The main question I was trying to decide on, is this: Does a measurable time elapse during the transport of such a message", which is "rushing from the sense organ to the brain, or of one, which the will sends from the brain through the motor nerves to the muscles?" [Helmholtz 1882-1895, II, 873] Helmholtz' answer was unambiguous: according to his experiments on the propagation of the nerve impulse published in the same year, 1850, one has to calculate for human beings a velocity of about 30 to 60 m/sec [Helmholtz 1882-1895, II, 877-878]. This result did not merely disprove Fechner's assumption. It put an end to the identification of the nervous principle with the simple flow of an electric current. In the following decades the dissimilarity of the two processes became increasingly clear, until at the beginning of the 20^{th} Century Julius Bernstein, one of the main authors of the membrane or ion-theory of the nervous stimulus, could characterize the comparison of nerve and telegraph wire as "untenable" and insisted on the "completely different nature" of both processes [Bernstein 1912, 19].

The fact that Bernstein felt at all obliged to comment on this, underlines the ongoing popularity of the analogy, which circulated with the writings of its protagonists a long time after their death. In 1912, the same year in which Bernstein wrote his ultimate verdict, a second edition of Emil du Bois-Reymond's popular lectures was published. Among others it included his lecture "Über tierische Bewegung", which had once given occasion to the quarrel with Helmholtz on the priority of the comparison between nerve and telegraph wire. But, as a closer look will show, they actually connected rather opposite ideas to one and the same device. In his lecture du Bois-Reymond developed a complete program of organic physics characterizing the human organism as a "dead machine", controlled by the "soul in the brain as the one and only both sensible and conscious region of the body" [du Bois-Reymond 1912, I, 47]. The relation between body and soul is defined now as a telegraphic one:

> For just as the central station of the electric telegraph in the Post Office in Königstraße [then the place in Berlin, where all Prussian telegraph lines converged] is in communication with the outermost borders of the monarchy through its gigantic web of copper wire, just so the soul in its office, the brain, endlessly receives dispatches from the outermost limits of its empire through its telegraph wires, the nerves, and sends out its orders in all directions to its civil servants, the muscles. [du Bois-Reymond 1912, I, 47-48]

Du Bois-Reymond proceeded to extend this analogy: he compared cut wires to severed nerves, pointed out that both nerve and wire do not show what they transmit and suggested that sometimes the brain as well as the telegrapher have problems identifying the sender of a received message. Above all he came to an astonishing conclusion:

> The wonder of our time, electrical telegraphy, was long modeled in the animal machine. But the similarity between the two apparatus, the nervous system and the electric telegraph, has a much deeper foundation. It is more than similarity; it is a kinship between the two, an agreement not merely of the effects, but also perhaps of the causes. [du Bois-Reymond 1912, I, 48]

With respect to du Bois-Reymond's first assertion, it so happened that two decades later the idea of an organic preformation of technology returned as guiding principle in Ernst Kapp's early 'technophilosophical' attempt with the concept of "Organprojection" [Kapp 1877]. The second assertion on the other hand reestablished the common ground of nervous system and electric telegraph at the very moment, in which Helmholtz' work on the velocity of the nerve impulse unmistakably displayed the different nature of the nervous principle and the electric current. However the telegraph du Bois-Reymond had in mind and the one Helmholtz imagined differed from each other in central aspects. I do not assume that they refer to different types of telegraphs, although in those days a number of apparatuses coexisted. Rather it appears that Helmholtz was chiefly interested in the relationship between the qualities of a single nerve and those of a *single telegraph wire*, whereas du Bois-Reymond placed his emphasis on *telegraphy as a system of wires* and compared it to the nervous system as a whole. The difference I would like to draw attention to will become clearer if we go back to Fechner for a moment. Some hundred pages before he takes up Soemmerring's comparison between nerve fiber and wire he explicitly makes some suggestions for improving Soemmerring's telegraphic apparatus. In a footnote he adds:

> I confess that it is very tempting to imagine that a future development of such a system of [telegraphic] connections may one day enable a similar, instantaneous, communication between the center of the government and its parts, as is produced by the nerves between the center of the organism and its limbs, apparently through a very analogous arrangement. (cf. the chapter on the Physiological Aspects of Galvanism). [Fechner 1829, 269fn]

Fechner's suggestion has a silent but important implication: it seems, he understood telegraphy first and foremost as a device for sending commands from the center to the periphery and correspondingly for him the nervous system, which in this case provided the model for telegraphy, much more resembled a number of strictly separated lines, than a system with manifold connections. After all, when these sentences were written in 1829, among the German countries only Prussia was making plans for a first optical telegraph line between Berlin and Koblenz on the Rhine [Beyrer 1995]. Twenty years later, when Helmholtz and du Bois-Reymond once again drew on the comparison, the situation had changed completely: About two-thousand kilometers of electric telegraph lines crossed Germany, private railway telegraphs as well as government telegraphs were in use, needle telegraphs and writing telegraphs were competing, and pioneers in electric telegraphy like the brothers Siemens and August Halske, who were both very well acquainted with Helmholtz and du Bois-Reymond, became the primal "system builders" (Thomas P. Hughes) of modern capitalism. It was this development of apparatuses and functions of telegraphy, combined with first systematic connections between already existing telegraph lines and a planful application of scientific knowledge to telegraphic technology, which created that systematic character, to which Helmholtz eventually alluded in his *Lehre von den Tonempfindungen* at the beginning of the 1860's.

The well-known passage, the first sentence of which has already been quoted above, concludes Helmholtz' discussion on the physiological correlate of the perceived tonal qualities. According to him, the „qualitative difference of pitch and quality of tone is reduced to a difference in the fibres of the nerve receiving the sensation, and for each individual fibre of the nerve there remains only the quantitative differences in the amount of excitement." [Helmholtz 1870, 223] This in turn implied nothing less than the assumption that qualitative differences in sensation do not correspond to qualitative differences in nervous excitement. Helmholtz claimed that this is as true for vision as it is for hearing and saw every transmission process in sensory nerves and motor nerves obliged to the "same simple scheme", namely of quantitative differences between stronger or weaker excitement. Once again however, the telegraph wire served Helmholtz as scheme of the scheme:

> Such a wire conducts one kind of electric current and no other; it may be stronger, it may be weaker, it may move in either direction; it has no other qualitative differences. Nevertheless, according to the different kinds of apparatus with which we provide its terminations, we can send telegraphic dispatches, ring bells, explode mines, decompose water, move magnets, magnetise iron, develop light, and so on. So with the nerves. The condition of excitement which can be produced in them and is conducted by them, is, so far as it can be recognised in isolated fibres of a nerve, everywhere the same, but when it is brought to various parts of the brain, or the body, it produces motion, secretions of glands, increase and decrease of the quantity of blood, of redness and of warmth of individual organs, and also sensations of light, of hearing, and so forth. [Helmholtz 1870, 224]

In contrast both to his own earlier interests and to previous references, Helmholtz develops the analogy in a very different direction here: he neither looks for empirical confirmations of an anatomical hypothesis, as did Soemmerring, nor does he try to identify the nervous principle and the electric current like Fechner. He also refrains from doing the opposite by stressing the incomparability between the nervous principle and the electric current, as he himself had done some years earlier. This time he emphasizes the uniformity of the process, which can be different in nature for the telegraph wire and the nerve, but which is characterized in both cases by the fact that there is only *one* acting principle.

So while his friend du Bois-Reymond chiefly alluded to the systematic aspect of telegraphy as a network, when comparing post office and telegraph wires to brain and nerves, Helmholtz finally found that both systems correspond with respect to the uniform character of the transmission process but differ in the nature of that process. Accordingly, some years later, in his famous lecture on "Die neueren Fortschritte in der Theorie des Sehens" (1868), this latest relation between organism and apparatus was reduced to its very essence:

> Nerve fibres and telegraphic wires are equally striking examples to illustrate the doctrine that the same causes may, under, different conditions, produce different results. [Helmholtz 1996, I, 205]

What struck Helmholtz here has nothing to do with similarities or dissimilarities between organic and technological objects. Instead, both objects appear as cases of a very general natural law, to which they comply. At this point, telegraphy wire ultimately ceased to be a working model or "simulacrum" of the nerve and the nervous system. For him, both now serve side by side as representations of something third: of a "doctrine", which became evident through them.

Conclusion

If one considers once again the various attempts from Soemmerring to Helmholtz to model the nerve (and the nervous system) along the materialities and capacities of the electric telegraph, it would be misleading to understand them all as ever refined efforts to answer one and the same question. Neither would it be appropriate to consider them as steps within one research program, which only needed to be executed. Depending on the particular context, telegraphy and in particular the telegraph wire became the scene of ever new questions, producing ever new aspects and qualities of the nerve and the acting nervous principle. In this respect, attributes of the model (for example the perfect insulation of Soemmerrings telegraph wires) were usually transferred to the object to be modeled, although sometimes (in Helmholtz' measurements of the velocity of the nerve impulse) the research object gained its characteristics precisely in difference to those of the model it was related to. In addition, one can observe very different ways in which the telegraph can function as a model. Soemmerring used the bundle of wires of his telegraph as a *material model* of the nerve and deduced the qualities of the nerve directly from his actual observations of the telegraph's functioning. Helmholtz and du Bois-Reymond in turn completely abstracted from any materially given telegraph and used the telegraph merely as a *model of thought* for physiological problems.

It is obvious that the way in which Soemmerring and to a certain extent Fechner too compared the telegraph wire to the single nerve comply best to Lenoir's suggestion that apparatuses of diverse origin can serve in physiological experiments as a kind of tangible representation for organic functions or properties. On the other hand it becomes clear that in the case of Helmholtz' and du Bois-Reymond's work the chosen model had an even stronger impact on the object to be modeled despite the fact that for them telegraphy 'only' served as thought model. This is in part due to the circumstance that Soemmerring and Fechner compared the nerve to the telegraph wire for a certain detail, whilst the former found in telegraphy the extensive model for a whole organic system. It therefore seems that the relation between the model and the object under research is strongest, when the model itself is *not* materially present in the investigation. To introduce a similar example: as a quick glance at Wilhelm Kühne's investigation on the chemical processes of the human retina in the late 1870's proves, neither a photographic apparatus nor photographic layers were present in his laboratory; Kühne did not even use microphotography to present his findings. Nevertheless, the whole set of photographic procedures like fixing and developing guided him conceptually in his investigations and determined the practical steps to be taken. For Kühne the retina could not only be compared to a light sensitive photographic layer: in order to understand its behavior, it was itself treated as such a layer [Kremer 1997; Hoffmann 2001]. In the same way the retina becomes the subject of photographic concepts here, one might suspect that Helmholtz' interest in the velocity of the nerve impulse was stimulated by a 'telegraphic concept' of the nervous system. It is at least striking that the question of velocity was indeed the main question of every discussion on telegraphy at the time.[7]

In general, the telegraphic modeling of the nerve and the nervous system in the course of the 19^{th} Century enables us to understand that the relations between a model apparatus and the organic entity investigated can be of manifold nature. As mentioned above, the possibility of materializing, representing or reworking the one or the other problem depends in part on the changing local context of the researchers. But, as this paper has shown, it is also a result of continuous changes within the field of electric telegraphy itself in the first half of the 19^{th} Century, changes which effected both the design of the apparatuses and the transmission principles. As a consequence, new relations to questions of nerve physiology were continuously becoming imaginable. The systematic character and unity of cause in telegraphy, which Helmholtz eventually discovered as thought model for the nervous system, was not available to Soemmerring five decades earlier. On the other hand, in Helmholtz' days telegraphy had become a system of apparatuses connected by one single wire: therefore the well functioning bundle of telegraph wires, which convinced Soemmerring of the insulating quality of the nerve fibers, was for Helmholtz at best a curious remnant of the past.

Finally I would like to point to the differences in the epistemic productivity between the various ways, in which the telegraph worked as a model in nerve physiology. In Soemmerring's case, the success of his

[7] Usually it is claimed that Helmholtz became aware of the velocity of the nerve impulse while he was stimulating a frog's crural nerve at different distances from its connection to the muscle [Olesko; Holmes 1993, 85-89]. This may be true but does not explain, *why* Helmholtz started to stimulate the nerve at different distances in the first place.

telegraphic apparatus made a certain hypothetical quality of the nerve fiber seem more likely. Here the benefit lies in a supposed structural similarity between the organic and the technological. Helmholtz on the other hand takes advantage of the obvious difference between the nerve's and the wire's transmission velocity in his remarks on the velocity of the nerve impulse. Eventually, as the example of Kühne's investigation on the chemical processes of the human retina shows, the apparatus can function as a kind of epistemic a priori, which directs every step of the research trail without being at all present in the actual experiments and observations. Each of these different possibilities to use apparatuses as models of the organic has a very specific impact on the results of a scientific inquiry and the theoretical conclusions deduced from them; and each of them can be implied when in the Mid Nineteenth-Century physiologists talk about organs or parts of organs in terms of apparatuses. The fact therefore that Helmholtz refers equally to the experimental arrangement and to the bones and nerve endings of the inner ear as apparatuses in his study on the quality of tone, does not say anything at all about *the particular way* the technological and the organic are related to each other here. On the contrary, as my argument should have shown, the widespread use of the word 'apparatus' in physiological publications of the time points to a number of ways, in which apparatuses could work as models in 19^{th} Century physiology — at least in the German speaking community. To put it differently: when, in those days, physiologists talked and thought about the nervous system in terms of telegraphy, they did not necessarily share a common concept, but simply made use of a common working model, which could lead to rather opposing results.

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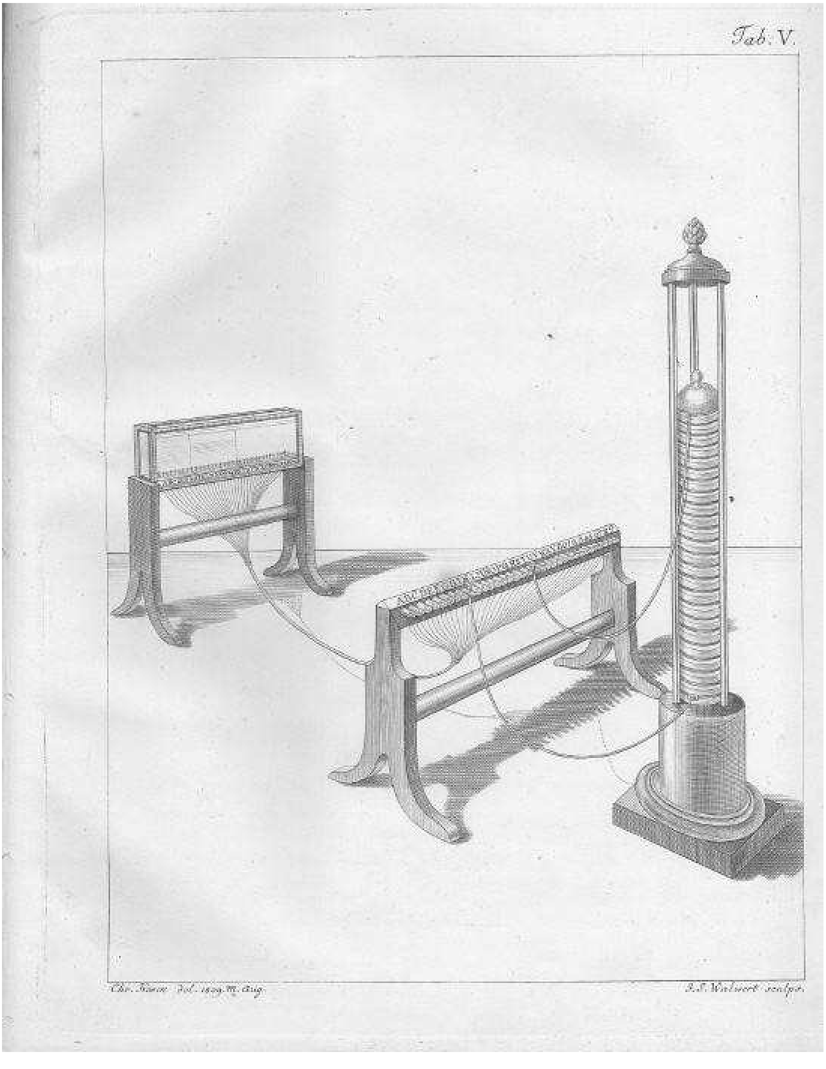

Fig. 1: Soemmerrings's telegraph. From right to left: Voltaic pile, transmitter, bundle of wires, and receiver [Soemmerring 1811, Plate V].

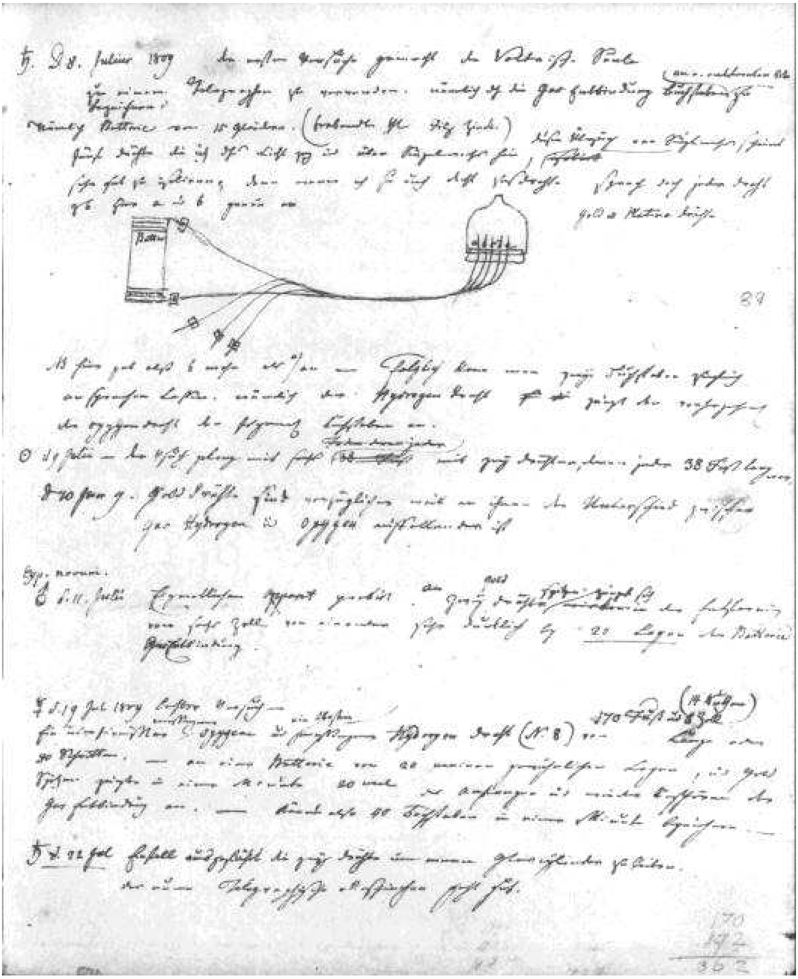

Fig. 2: Sketch of the telegraph cable, from Soemmerring's experimental diary, dated 8^{th} July, 1809. Above the sketch: "five wires, which I pulled through the candle and then through sealing wax, this coat of sealing wax seems to insulate very well, because even when I bound them together tightly every single wire, here for example a and b, reacted exactly." [Soemmerring 1786-1823, 89].

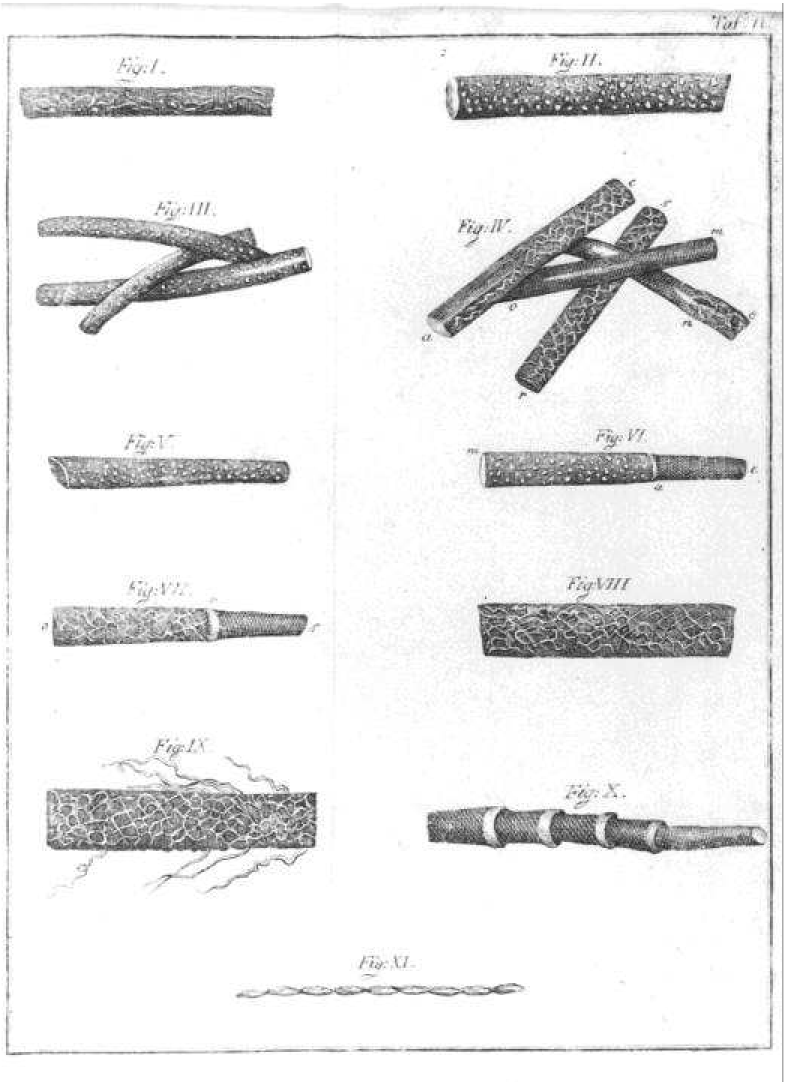

Fig. 3: Representations of the single nerve cylinder according to Felice Fontana [Fontana 1781, II, Plate IV]