Intentionality and Symbolic Construction. The Phenomenological Background of Weyl's Philosophy of Physics

Harald A. Wiltsche

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Further Materials: CV, Letters of Support by T. Ryckman, S. French and W. Hopp

1 Introduction[1]

One of the more curious aspects of the development of 20^{th} century philosophy is the infamous analytic/continental-divide. Although there are growing doubts about its philosophical significance, the analytic/continental-split continues to shape the face of professional philosophy. In many areas the reality is still that philosophers who associate themselves with one tradition tend to ignore the other. This state of mutual ignorance is particularly noticeable in philosophy of science, where influences from outside the well-established canon of analytic philosophy are even scarcer than in other fields.

There are, of course, historical reasons for the relative absence of continental influences on contemporary philosophy of science. As has been argued (Ryckman 2005, chapter 3), it was the reception of Einstein in particular that transformed the philosophical landscape in favor of the emerging analytical movement. Schlick was perhaps the most vocal proponent of the view that the general theory of relativity decisively refuted all forms of "critical" philosophical reflection on the sciences that did not fit into the methodological framework of logical empiricism (Coffa 1991, chapter 10; Howard 1994; Friedman 1999, chapter 1; Ferrari 2016). Although there were eminent philosophers (e.g. Cassirer 1953, 409-429) and physicists (e.g. von Laue 1921, 42) who disagreed with this view, it soon became a commonly shared background assumption for most philosophers of science. The victory of logical empiricism over "critical" philosophy "resulted—if one judges from the subsequent appearance of the discipline of philosophy of science—in near unconditional surrender of the terrain of philosophical discourse about science to logical empiricism, i.e., to analytic philosophy" (Ryckman 2012, 25).

A central assumption underlying the planned research project is that continental philosophy does not play a relative minor role in philosophy of science because of shortcomings that are intrinsic to its methodological outlook. At least in part, its relative absence is rather to be explained in terms of external factors such as the catastrophic political events that swept across Europe in the first half of the 20^{th} century. A major aim of the planned research project is to substantiate this thesis by offering a critical reconstruction of a still understudied approach to science that lies outside the trajectory of analytic philosophy and that—partly for this very reason—did not gain the traction needed to establish itself as a real factor in philosophy of science. The approach in question is due to H. Weyl (1885-1955), one of the most influential mathematicians and physicists of the 20^{th} century.

Although not too well known in philosophical circles, Weyl is a towering figure in 20^{th} century mathematics and science. Since an exhaustive list of his achievements would exceed the scope of this proposal, I will restrict myself to just a few of Weyl's most salient contributions. In pure mathematics, Weyl's premier achievement is probably his general theory of the representations and invariants of the classical Lie groups, which was later applied to the analysis of quantum mechanics. Weyl also contributed to the foundations of mathematics, where he first defended a form of predicativism and then an intuitionistic

[1]This proposal is a revised and resubmitted version. There are no ethical concerns for carrying out this project. I am thankful to two anonymous referees for their helpful comments.

view similar to that of L.E.J. Brouwer. In theoretical physics, one of Weyl's most enduring achievements grew out of the attempt to unify electromagnetism and general relativity. Although Weyl's unified field theory was rejected by most of his contemporaries—and by Einstein in particular—, it contained the notion of gauge invariance, a notion that still proves to be essential in contemporary physics (cf. section 2). Furthermore, in the fifth German edition of *Space-Time-Matter* (Weyl 1923a) Weyl predicted the cosmological redshift, six years before the effect was empirically established by E. Hubble. Finally, it was on the basis of his analysis of mass in terms of electromagnetic field energy that Weyl proposed the topological idea of "wormholes" or "Schläuche von eindimensional unendlicher Erstreckung", as Weyl initially called them (1921, 557).

The list of his scientific accomplishments could be easily extended further (Hawkins 2000, part 4; Goenner 2001; Straumann 2001; Coleman and Korté 2001; Bell and Korté 2015) but it suffices to show that Weyl's influence on 20th century mathematics and physics was enormous. Yet, there are further reasons why Weyl deserves not only historical, but also philosophical attention. First, one would be hard pressed to find a scientist of Weyl's stature who invested more effort into reflecting on the nature of scientific cognition from a philosophical point of view. Weyl's interest in philosophy already becomes apparent in his groundbreaking 1918 introduction to general relativity, *Space-Time-Matter*. Yet, Weyl's preoccupation with philosophy reached its peak in 1926, when his monograph *Philosophy of Mathematics and Natural Sciences* came out. These sources, together with Weyl's little book *Symmetry* (Weyl 1952b), the collection of lectures published under the title *Mind and Nature* (Weyl 2009) and numerous philosophical remarks scattered throughout his oeuvre, offer an invaluable perspective on how one of the most distinguished scientists of our time seeks to make philosophical sense of his scientific practice.

The second reason to put Weyl at the center of the planned research project has to do with the specifics of his philosophical orientation. When looking at his philosophy from a contemporary perspective, one can easily agree with the observation that Weyl wrote "more like a 'continental' than an 'analytic' about mathematics and science" (Ryckman 2012, 28). For instance, who would have expected to find the following passage in a textbook on general relativity that was so widely read that it went through five editions in only six years?

> In perception I see this chair, I am directed towards it. I 'have' the perception, but it is only when I make this perception in turn the intentional object of a new inner perception (a free act of reflection enables me to do this) that I 'know' something regarding it (and not only regarding the chair alone) [...]. In this second act the intentional object is immanent, i.e. like the act itself, it is a real component of my stream of experiences, whereas in the primary act of perception the object is transcendent, i.e. it is given in an experience of consciousness, but is not a real component of it. (Weyl 1952a, 4; translation modified)

As this and several other passages indicate, Weyl's thinking is deeply entrenched in philosophical traditions that are usually considered to belong to the continental camp. Weyl's thinking was influenced by the writings of Leibniz, Fichte, Meister Eckhart, Jaspers, Heidegger and—most importantly in the context of this proposal—E. Husserl. It is this unusual philosophical background that makes Weyl the focal point of the planned research project. Although Weyl never offered a systematic account of his philosophical views, the ideas contained in his writings are what come closest to a genuinely continental philosophy of science.[2]

2 Current State of Research

Recent years have seen a steady increase in literature dealing with different aspects of Weyl's oeuvre. Given his multi-disciplinary background, it is not surprising that Weyl has sparked the interest of philosophers and historians of mathematics (van Dalen 1995; Scholz 1995; Feferman 1998; Bell 2000; Mancosu 2002; van Atten, van Dalen and Tieszen 2002; Folina 2007) as well as philosophers and historians interested in the physical sciences (Ryckman 2003a; Scholz 2004; 2011; Sieroka 2010a). Furthermore, many authors pay special attention to the relations between Weyl and Husserl, either by addressing the latter's influence on the former (da Silva 1997; Feist 2002; 2004b; Mancosu and Ryckman 2002; Ryckman 2003b; Marion 2004; Tieszen 2005; Ryckman 2005; 2012; da Silva 2013) or by emphasizing the alleged divergences between the two (Bell 2004; Kerszberg 2007; van Atten 2008; Sieroka 2009, 2010b; Toader 2013; 2014).

In light of the historical facts, the focus on the role of phenomenology in the formation of Weyl's thought is more than justified: Besides close personal contacts and an extensive correspondence (cf. Ryckman 2005; van Dalen 1984; Schuhmann 1994, 285-296), references to Husserl are easy to find in Weyl's writings. For instance, in the preface to *The Continuum* Weyl flatly states that he is in full agreement with Husserl "[c]oncerning the epistemological side of logic" (Weyl 1987, 2). Matters are even clearer in the case of his monograph *Space-Time-Matter*. A good portion of the introduction to Weyl's celebrated introduction to general relativity consists of a highly condensed summary of Husserl's theory of intentionality. In a footnote Weyl writes that "[t]he detailed development of these ideas follow very closely the lines of Husserl in his 'Ideen zur reinen Phänomenologie und phänomenologischen Philosophie'" (Weyl 1952a, 319). Husserl also looms large in Weyl's *Philosophy of Mathematics and Natural Science*. Even if one only takes explicit references as a measure, Husserl is among the most cited authors. Apart from a contribution to a Festschrift commemorating Husserl's oeuvre (Weyl 1940), there are also

[2] There are, of course, well-known problems with the analytic/continental-distinction. First, although the distinction is still widely used, no convincing criteria have been offered to draw it in in a sufficiently clear and non-arbitrary way (cf. Rinofner-Kreidl and Wiltsche 2016). Second, and even more important in the context of this proposal, there is an obvious sense in which it is somewhat misleading to label Weyl as a representative of a "continental" approach to philosophy of science: Since the distinction did not even exist when his most relevant writings were published, we should always keep in mind that referring to Weyl as a philosopher with continental leanings is a backwards projection of a contemporary distinction. Finally, it should be noted that it would be an overstatement to claim that no continental contributions to philosophy of science exist. Cf., e.g., Kockelmans and Kisiel 1970; Gurwitsch 1973; Heelan 1983; Hardy and Embree 1992; Feist 2004a; Gutting 2005; Hyder and Rheinberger 2010; Hardy 2013; Seebohm 2015.

numerous passages in which Weyl refers to Husserl without mentioning him by name.

Of course, one could question whether these references amount to more than paying mere lip service to the phenomenological movement. Yet, there are good reasons to believe that Weyl's commitment to phenomenology is more substantial. Not only did, as will become apparent in section 4, phenomenological motives influence Weyl's metatheoretical views about the nature of scientific cognition. As T. Ryckman has shown, phenomenological concepts such as the notion of *Evidenz*, the methods of eidetic and phenomenological reduction as well as Husserl's transcendental idealism also "comprise an essential part of the 'context of discovery' of gauge principle, one of the most productive ideas of 20$^{\text{th}}$ century theoretical physics" (Ryckman 2005, 110).

It would go beyond the scope of this proposal to review Ryckman's argument in detail (cf. Ryckman 2003b; 2005, chapters 4-6; 2009). However, the main point of Ryckman's groundbreaking work may be summarized as follows: In a similar sense in which the late Husserl sought to clarify the very meaning of mathematical thought by means of an "archaeology" of geometry (cf. Husserl 1970), Weyl's early work in theoretical physics is to be understood as an "archaeology" of general relativity that is supposed to elucidate the very meaning of the "posit of reality" made within Einstein's theory. Weyl's phenomenological reflection starts from a critical evaluation of Riemannian geometry, the geometry on which general relativity is based. In Riemannian geometry it is meaningful to speak of direct length comparisons between vectors at distant points of a manifold. On Weyl's view, however, this possibility of direct distant length comparison represents "a residual element of finite geometry" which is upheld "without any substantial reason" (Weyl 1923b, 202). Instead of naively presupposing the global availability of a measuring rod, Weyl sought to recast general relativity in the framework of a "purely infinitesimal geometry" that only "*recognize*[s] *the principle of the transference of a length from one point to another point infinitely near to the first*" (Weyl 1923b, 203). Weyl's non-Riemannian geometry thus permitted the unit of scale to vary (smoothly) from space-time point to space-time point; from this new degree of freedom, he was able to show that Maxwell's electromagnetism, in addition to Einstein's gravitation, could be incorporated into the metric of space-time. Hence was born the contemporary idea that a physical theory must be "gauge invariant", i.e., remain invariant under transformation of certain local degrees of freedom.[3] As reinterpreted in the context of quantum mechanics by Weyl himself in 1929, the derivation of electromagnetism from gauge freedom pertains not to a factor of scale but to the arbitrary phase of the electron wave-function represented by the Abelian (i.e., commutative) group U(1). Yang and Mills in 1954 further generalized Weyl's idea of local gauge invariance to non-Abelian Lie groups (O'Raifeartaigh 1997); it is no overstatement to say that non-Abelian gauge fields are the very core of the Standard Model

[3]Weyl later commented the history of the principle of gauge invariance as follows: "Aus dem Jahre 1918 datiert der von mir unternommene erste Versuch, eine einheitliche Feldtheorie von Gravitation und Elektromagnetismus zu entwickeln, und zwar auf Grund des Prinzips der Eichinvarianz, das ich neben dasjenige der Koordinaten-Invarianz stellte. Ich habe diese Theorie selber längst aufgegeben, nachdem ihr richtiger Kern: die Eichinvarianz, in die Quantentheorie herübergerettet ist als ein Prinzip, das nicht die Gravitation, sondern das Wellenfeld des Elektrons mit dem elektromagnetischen verknüpft." (Weyl, quoted in Straumann 2001, 146)

of contemporary particle physics of which the most recent triumph is the experimental detection of the Higgs boson at CERN in 2012.

What makes Weyl's proposal particularly interesting from a phenomenological perspective is the philosophical rationale that underlies his reconstruction of general relativity. On Weyl's view, only the so-called tangent space—an infinitesimal Euclidean space associated with every point in the space-time manifold—is the locus of *Evidenz* for an idealized cognizing subject (Weyl 1931). And this, of course, is also the reason for Weyl's reformulation of general relativity: While the displacement of vectors within the tangent space is intuitively evident and thus phenomenologically permissible, finite displacements take the vectors beyond the sphere of what can be intuitively given in *Evidenz*. Hence, Weyl's reconstruction of Einstein's theory in the framework of a purely infinitesimal geometry was guided by a process of "*original sense-explication*" (Husserl 1969, 9) and thus by the phenomenological demand "*to work completely consciously, 'to trace back to Evidenz'*" (Husserl 2008, 440).

3 Aims of The Planned Research Project

Although T. Ryckman will play an important role in the planned research project (cf. section 6), the project's overall aim differs from that of his previous works in some key respects. While Ryckman's main focus is on the role of phenomenology for Weyl's physics, *the planned research project concentrates on the role of phenomenology for Weyl's meta-theoretical views about the nature of scientific cognition.* As has been indicated, the project proceeds from the assumption that Weyl's writings contain several more or less developed ideas towards a philosophy of science that is firmly rooted within the framework of Husserlian phenomenology. The main objective of the research project is to identify and critically evaluate these ideas, and to turn them into a systematic whole. Ideally, the final outcome of the project will be the outline of a genuinely phenomenological philosophy of science that opens up new ways to think about the nature of science and scientific cognition.

To be sure, discussions of some of Weyl's phenomenologically inspired views about science do exist in the secondary literature. However, what makes the planned research project worth undertaking is that only a fraction of the relevant passages have been identified and that, consequently, the true scale of Weyl's commitment to phenomenology has been underestimated. There are, as I believe, reasons why many of Weyl's allusions to Husserl have gone unnoticed. In some cases, Weyl's references to phenomenology are easy to identify, either because Husserl is mentioned explicitly or because Weyl's wording is so distinctively phenomenological that the intended reference is impossible to miss.[4] In many other cases, however, Weyl's allusions to Husserl are more concealed because, first, Husserl is not mentioned explicitly and, second, the passages to which Weyl refers

[4] A good example is Weyl's discussion of coordinate systems, which are described as "the unavoidable residue of the annihilation of the ego" (Weyl 1987, 94). This, of course, is a direct reference to section 49 of *Ideas 1* in which Husserl talks about pure consciousness as "the residuum after the annihilation of the world" (Husserl 1983, 109).

are not particularly well known.[5] Matters are even worse for scholars who rely on English translations. Since most of Weyl's translators were unfamiliar with the peculiarities of Husserl's technical language, many English passages in which Weyl discusses genuinely phenomenological topics border on the unintelligible.[6] It is in light of these facts that a thorough and phenomenologically informed re-reading of Weyl will shed new light on his philosophical views on science and on his commitment to Husserlian phenomenology. In order to substantiate this claim, one concrete case study shall be discussed in section 4. Before that, however, two further remarks about the scope of the planned research project are called for.

The first point concerns the asserted relation between Weyl and Husserl. As has become apparent, one of the central assumptions underlying the planned research project is that phenomenology exerted an important influence on Weyl and that "his engagement with Husserl never ended" (Ryckman 2005, 115). However, this assumption must be qualified. To begin with, Weyl was no disciple of Husserl who followed the latter's program blindly. Weyl was a creative mind who took inspirations from different sources and who did not shy away from expressing his misgivings about certain aspects of Husserlian phenomenology. These critical remarks (especially Weyl 2009a) have led some commentators to believe that Husserl's influence on Weyl is much less significant or—even stronger—that Weyl's and Husserl's philosophical views are incompatible. Although a critical evaluation of these dissenting voices will be an important task, it is crucial to note that the success of the planned research project is not threatened by certain factual inconsistencies between Husserl and Weyl. As Husserl made clear on various occasions, his philosophy is not a fixed system of eternal truths, but rather a "methodical working philosophy" (Husserl 1970, 100), i.e. a methodological toolbox that is designed to carry out increasingly sophisticated descriptions of the essential structures of consciousness. In light of this understanding of phenomenology, the primary question is not whether Weyl's philosophical views can be brought in line with every detail of Husserl's writings. Rather, the question is how one of the most influential scientists of the 20$^{\text{th}}$ century made use of the phenomenological method in order to elucidate the nature of scientific cognition. Seen from this perspective, the aim of the planned research project is not only to promote our understanding of Weyl by reading him against the background of

[5] Consider, for instance, the following definition of a continuous manifold: "Die Mf [Mannigfaltigkeit; H.A.W.] ist stetig, wenn die Punkte so miteinander verwachsen sind, daß es unmöglich ist, einen Punkt für sich herauszuheben, vielmehr immer nur zusammen mit einem vag begrenzten ihn umgebenden Hof, mit einer *'Umgebung'*." (Weyl 1988, 2) While some have seen traces of Fichte's philosophy in this passage (Dusek 2006), readers familiar with the phenomenological tradition will not fail to recognize the notions "Hof" and "Umgebung" as technical terms that are used by Husserl to describe the horizonal givenness of objects (Husserl 1973a, 185; 1983, sections 35 and 83; 1997, sections 54-55; 2002, 300). It should be noted, of course, that the notion of "Umgebung" was customary in the context of topology at least since Hausdorff. But the fact that Weyl naturally combines both notions, "Hof" and "Umgebung", strongly suggests a Husserlian background of this passage.

[6] To give just one example, in the introduction to *Space-Time-Matter* Weyl writes that "in dem primären Wahrnehmungsakt [...] ist das Objekt *transzendent*", which means that in the natural attitude the object is experienced as if it were entirely independent from human consciousness. In the English translation, however, Weyl is translated as saying that "in the primary act of perception the object is *transcendental*", which renders the passage unintelligible.

Husserl. The aim is also to appreciate Weyl's use of the phenomenological method as a welcome opportunity to challenge some of the orthodoxies of Husserl's official doctrine.

The second point concerns the relation between the historical and the normative dimensions of the planned research project. As has been pointed out, the starting point is Weyl, whose oeuvre will be analyzed with special attention to the phenomenological background of his thinking. However, it is important to note that the project cannot stop at this exegetical level. On the one hand, the fact that he never offered a systematic account of his philosophical views will make it inevitable to go beyond Weyl and to fill in the blanks in his meta-theoretical writings on science. On the other hand, one of the main objectives of the planned research project is to determine whether a phenomenological account could be a serious contender in today's philosophy of science. Hence, it will be necessary to enter a critical dialogue with contemporary positions and thus with topics that were not directly addressed by Weyl. Building on my previous work at the intersection between "mainstream" philosophy of science and phenomenology (Wiltsche forthcoming a; forthcoming b; 2018; 2016a; 2016b; 2015; 2013a; 2013b; 2012; 2011; Fehige and Wiltsche 2013), my aim is to promote a Weylean position in debates about, for instance, scientific realism, scientific modeling or thought experiments.

4 Case Study: The Constitution of Electric Fields

As has been pointed out, a phenomenologically informed re-reading of Weyl is highly desirable because many of his allusions to Husserl have gone unnoticed. The aim of this section is to substantiate this claim by discussing an exemplary passage from *Philosophy of Mathematics and Natural Science*.[7] The case study is instructive for three reasons: First, it is impossible to appreciate the full significance of Weyl's argument without paying attention to its phenomenological background. Second, the phenomenological background can easily be overlooked because explicit references to Husserl as well as a distinctively phenomenological terminology are missing. Third, the case study underscores the relevance of Weyl's meta-theoretical views for contemporary discussions in "mainstream" philosophy of science.

Recent years have seen a vast increase in literature dealing with the role of models in science (Morgan and Morrison 1999; da Costa and French 2003; Bailer-Jones 2009; Suárez 2009; Frigg and Hartmann 2012; Gelfert 2016). Within the framework of this research proposal, three questions are particularly relevant. First, there is the epistemological question of how models enable us to learn something about the world, and of how cases of model-based knowledge acquisition compare with more mundane cases where knowledge is gained without the use of models (Magnani and Nersessian 2002; Downes 2011). Second, there is the question of representation: According to a widespread view, models can only teach us something about the world if we assume that they successfully repre-

[7] Of course, one may wonder whether this case study is paradigmatic for Weyl's overall philosophical position. Although a conclusive answer to this question will have to wait until the project has actually been carried out, the case study shows, at the very least, that phenomenology was a determining factor for Weyl's thinking up until the 1930ies.

sent certain aspects of reality. But this raises the question of how the representational capacities of models are brought about: In virtue of what is a model a representation of a particular target system (Díez and Frigg 2006; Frigg and Nguyen 2016)? Third, there is the question of ontology: While material models such as scale models may not pose much of a problem, the ontological status of physically unrealizable models is not so easy to determine. Are they set-theoretical structures, equations, fictional entities, descriptions, or something else entirely (Contessa 2010; Toon 2012)?

Browsing through the literature, one may get the impression that these questions were put on the philosophical agenda only recently,[8]and that virtually all contributions operate within the framework of analytic philosophy. This, however, is not the case. Besides Husserl's early anticipations of what is nowadays known as the "semantic view" (Mormann 1991), elements of a philosophical theory of scientific modeling can also be found in Weyl's writings, for instance in section 17 of *Philosophy of Mathematics and Natural Science*.

Underlying Weyl's argument is the general epistemological thesis that knowledge about the world is constituted or "distilled out" of the immediately given through what Weyl calls "symbols" or "symbolic constructions" (cf. Weyl 1948; 2012). Following this thesis, Weyl writes that

> [a] typical example of this is furnished by a body whose solid shape constitutes itself as the common source of its various perspective views. This would not happen unless the point from which it is viewed could be varied and unless the different viewpoints actually taken present themselves as instances of an infinite continuum of possibilities laid out within us. [...] Thus *perspective* teaches us to derive the optical image from the observer's location relative to the body. (Weyl 1949, 113)

Without explaining this any further, Weyl goes on to discuss his actual example, "the constitution of the concepts 'electric field' and 'electric field strength'" (Weyl 1949, 113). Weyl asks us to assume that a weakly charged test particle is put at some place P between two charged conductors. Whenever the test particle is put at the same place, the particle experiences the same vector force F. Conversely, if different test particles are put at different places, we realize that the force acting on the particles depends on the place at which the particles are put. According to Weyl, we can conclude from this that the vector force at any given place P can be mathematically described as

$$\vec{F}(P) = e \cdot \vec{E}(P),$$

where the vectorial factor $\vec{E}(P)$ represents the electric field strength at point P and the scalar factor e the charge of the test particle. While $\vec{E}(P)$ is a point function that is independent from the state of the test particle, e is independent from the position of the particle or from the charged conductors because it is determined exclusively by the inner

[8]This, of course, is only true of models as representational vehicles in scientific contexts. As one reviewer has rightly pointed out, interesting things could be said about Tarski's development of model theory that bore influences from Husserl's work on a "theory of theories" in the *Logical Investigations*.

state of the particle. After introducing the example in this way, Weyl offers the following interpretation:

> [W]e start from the force as the given thing; but the facts outlined lead us to conceive of an electric field, mathematically described by the vectorial point function $\vec{E}(P)$, which surrounds the conductors and which exists, no matter whether the force it exerts on a test particle is ascertained or not. The test particle serves merely to render the field accessible to observation and measurement. The complete analogy with the case of perspective is obvious. The field $\vec{E}$ here corresponds to the object there, the test particle to the observer, its charge to its position; the force exerted by the field upon the test particle and changing according to the charge of the particle corresponds to the two-dimensional aspect offered by the solid object to the observer and depending on the observer's standpoint. (Weyl 1949, 114)

What to think about this interpretation? To begin with, it seems safe to say that the physics behind Weyl's example is rather straightforward. However, the situation is much more complicated as far as questions of philosophical interpretation go. The first question concerns the way in which Weyl sets up his argument: If Weyl wants to tell us something about models, why does he start with perspectivity and hence with a phenomenon that is characteristic of perceptual experience? Secondly, what Weyl is actually saying about perspectivity is also far from being self-explanatory. While it may be uncontroversial to regard perspectivity as an important feature of perceptual experience, it is much less clear what it means to refer to different perspectival viewpoints "as instances of an infinite continuum of possibilities laid out within us" (Weyl 1949, 113). A third question concerns Weyl's comparison between perception and cases of model-based reasoning. The point of Weyl's argument appears to be that there is a "complete" and "obvious" analogy between perceptual perspectivity and the probing of electric fields through test particles. But what exactly is the analogy offered here? On the basis of Weyl's text alone, the point of his comparison is nowhere as obvious as he himself seems to believe.

If one strictly adheres to the letter of Weyl's text, it is almost impossible to appreciate the full significance of his argument. In line with what has been said before, this is because Weyl's argument presupposes several phenomenological key concepts without, however, making this explicit. Hence, it is necessary to become acquainted with the phenomenological notion of horizonal intentionality in order to get a grip on Weyl's position.

4.1 The Phenomenological Background

A provisional version of Husserl's theory of intentionality is best introduced by means of a concrete example.[9] Suppose that, upon entering my office, I see my bike leaning

[9] For more detailed presentations, cf. Rinofner-Kreidl 2000; Drummond 2003; Zahavi 2003, Moran 2005; Smith 2007. It is also only for the sake of simplicity that I am relying on Husserl's early terminology. As is well known, Husserl's terminology (as well as the underlying theory of intentionality) underwent a number of modifications in *Ideas 1* (Husserl 1983, sections 87-135).

against the bookshelf. In order to account for this episode, it is necessary to distinguish at least three basic components. The first component is the *conscious act*—in this example a visual experience of perception. The conscious act is a concrete mental event. It is something that transpires in my mind or yours and whose content—the immanent content, as the early Husserl calls it—is strictly private. When I see my bike leaning against the bookshelf, then the immanent content is the actual sensuous data I am experiencing at one particular point in time.

The conscious act is a temporal occurrence in the subject's mind and its content is strictly private and unshareable. This distinguishes the act and its immanent content from the *intentional object*. In the example at hand, the intentional object is the bike that is leaning against the bookshelf and that can be perceived by different subjects through different perceptual acts. In the case of veridical perceptions, the relation between conscious act and intentional object is rather straightforward: When I am intentionally directed towards my bike, then the intentional object is no other than the real physical bike that is leaning against the bookshelf. With regard to perception, Husserl is thus defending a form of direct perceptual realism, denying that the perceptual contact with objects is mediated by an intramental representation of the intended object (Husserl 1983, section 90; Naberhaus 2006).

So far, I have distinguished two components, the conscious act and the intentional object. But these two components are not yet sufficient to give an adequate description of the example under consideration. In order to see why, consider the following modification of the example: Suppose that Timmy and I are entering my office when a bike catches our attention. Since I immediately realize that it is *my* bike, I automatically perceive the bike as *my* bike. Timmy, however, does not know that the bike belongs to me and thus perceives the bike differently, namely as just another race bike.

This modified example is significant because it shows that the distinction between conscious act and intentional object does not yet suffice to do justice to the complexities of our mental life. Timmy and I are both subjects who are intentionally directed towards the same physical thing. In this particular situation, however, we are intending the same thing differently, namely through different *meanings* or *senses*; while I perceive the bike as *my* bike, Timmy perceives the bike in a different manner, namely as just another race bike. Hence, in order to account for the fact that subjects are able to refer to the same object through different meanings or senses, we must distinguish another essential component, the *intentional content* of the act.

What precisely is the intentional content? To begin with, the intentional content is specified by the description of what I see, just as I see it. So, when Timmy says that he sees a race bike and when I say that I see my bike, the difference between our descriptions is due to the fact that the same object is intended differently through different intentional contents. The second thing is that, unlike conscious acts and their immanent contents, intentional contents are public and shareable. When I perceive my bike, my sensory input is strictly private. However, it is nevertheless possible that two subjects are directed towards the same intentional object through the same intentional content. In order to account for this, the early Husserl proposed a view according to which intentional contents are much like Fregean Gedanken. On this view, intentional contents are ideal species that can be instantiated by different subjects through different concrete conscious acts (Husserl 2001b, investigation 5, section 25; Mohanty 1977). Yet, the mature Husserl became increasingly dissatisfied with this solution and proposed a more sophisticated interpretation. On Husserl's refined view, the intentional content—or of the *noema*—is partly understood in terms of *horizons of possibilities* or *horizons of possible experiences* (Husserl 1973b, section 8; 1983, sections 27-30; 1989, section 15; 1999, sections 23-29; 2001c, part 2). Perhaps the easiest way to gain a provisional understanding of what this means is again through an example.

Suppose that Timmy and I are traveling through Fake Barn County. At one point during our ride, we perceive a physical structure that looks like a barn. In this situation, Timmy and I are having conscious acts that present as their immanent content the sensuous data that lies beneath the two-dimensional appearance of a barn-like structure.[10] But there is a difference between me and Timmy: Since Timmy does not know that we are traveling through Fake Barn County, it is natural for him to perceive the barn-like structure as a real barn. I, on the other hand, know of the peculiarities of the area through which we are traveling. As a consequence, it is natural for me to perceive the barn-like structure as what it really is, a fake barn. Now, coming back to the interpretation of intentional contents, what is the difference between perceiving an object as a real barn and perceiving an object as a fake barn? According to Husserl, part of the difference is that Timmy and I are projecting the appearances against the background of *different horizons of possible experiences* (Hopp 2011, 56-60). For instance, when Timmy perceives the barn-like structure as a real barn, he automatically has the possibility-driven anticipation that further experiences will reveal a backside that resembles the frontside in a manner typical of real barns. This anticipation is an essential part of what it means for Timmy to perceive the structure in front of him as a real barn. I, on the other hand, perceive the structure as a fake barn and thereby automatically anticipate the backside to be different from the frontside in a manner typical of fake barns. If we decide to walk around the barn-like structure, my horizon of possibility-driven anticipations will likely be confirmed by further experiences. Timmy, on the other hand, will have to realize that he has conceptualized the sensuously given in a way that is incompatible with how things are in Fake Barn County.

In the later stages of his career, the notion of horizon became increasingly important for Husserl's account of intentionality (Smith and McIntyre 1982, chapter 5; Geniusas 2012). Husserl realized that intentionality is not like an arrow that picks out singular objects in a more or less static fashion. Rather, intentional directedness is a dynamic process in which ever-changing appearances are continuously projected against a horizon of possible further experiences. The perceptual encounter with physical things is paradigmatic in this respect: At each and every moment in time, what is given is the perspectival, two-dimensional appearance of a thing. But, of course, what is meant in perception is not a two-dimensional appearance, but rather a three-dimensional object in space. Hence, there is a describable discrepancy between what is meant through a particular intentional act ("This fake barn over there") and what is sensuously given ("The fake barn's facing side

[10] Cf., for details on the relation between sensuous data and interpretation, e.g. Hopp 2008.

with its momentarily visible features"). Phenomenologically construed, this discrepancy presents no problem that must be somehow remedied, e.g. by proposing a theory that explains how seemingly disconnected profiles add up to an identical thing in space. The fact that intending is always an "intending-beyond-itself" (Husserl 1960, 46) is rather to be treated as a phenomenologically discoverable feature of experience itself. We always perceive objects as something, i.e. in a certain manner or from a certain perspective. But to perceive an object as something means to constitute the object in a certain way by constantly projecting appearances against a horizon of possible further experiences. Whenever we change our vantage point and thus receive new sensory input (Husserl 1997, sections 3-5), the resulting appearances have to be harmonized with the horizon through which the object is intended. If this harmonization succeeds, we know that we have conceptualized the object in a plausible way. If the harmonization fails, we have to accept that the horizon through which we have intended the object needs to be revised. Let us now, with these remarks as a backdrop, return to Weyl.

4.2 The Case Study Explained

As has been pointed out, Weyl proceeds from the thesis that the world around us is constituted or "distilled out" of the immediately given through "symbols" or "symbolic constructions". On Weyl's view, "[a] typical example of this is furnished by a body whose solid shape constitutes itself as the common source of its various perspective views". And, as Weyl adds, this "would not happen unless the point from which it is viewed could be varied and unless the different viewpoints actually taken present themselves as instances of an infinite continuum of possibilities laid out within us" (Weyl 1949, 113). Now that we have familiarized ourselves with the phenomenological notion of horizonal intentionality, we can appreciate the full significance of these remarks. Assume that you are standing in front of a barn. In this situation, your perceptual experience is about a physical object even though only parts of the objects are actually in your visual field. This suggests that the content of your perceptual experience is not fully determined by the sensory input. But if the intended objects always transcend the perspectival given, how do subjects manage to be intentionally directed to three-dimensional objects in space? As Weyl indicates, part of the answer lies in the fact that the vantage point from which the object is perceived can be varied. It is through the movement of our body and the corresponding variation of perspective that the perceived object reveals previously concealed sides and properties. Certain features of the object remain invariant, and it is these invariances that are essential for constituting the perceived thing as objectively existing.

However, as Weyl also realizes, kinaesthetic movements and the resulting variation of perspective is just part of the story. The role played by an object's newly perceived profile essentially depends on how the object is conceptualized through particular intentional contents. Suppose that you are walking around a barn and that its backside turns out to look exactly how you anticipated it. In this situation, the newly perceived backside plays a distinctive role in the process of experiencing for two reasons: First, as Weyl recognizes, the newly perceived backside presents itself as one concrete instance of the open horizon of experiences in which new parts, sides and properties of the barn would be perceptually exhibited. And secondly, the experience of the backside can be harmonized with the horizon and thus with the intentional content through which the barn was initially intended. By intending the object in front of you as a barn, you have implicitly anticipated the object to reveal a backside that resembles its frontside in a manner typical of barns. And since this possibility-driven anticipation was corroborated after viewing the object from a new perspective, the way the object was initially conceptualized turned out to be adequate. This interplay of conceptualization and subsequent harmonization is precisely what makes a mental episode a successful perceptual encounter with a thing: Objects or states of affairs are perceived in a certain manner by projecting the sensory input against a horizon of possible experiences. The process of perception consists in the "probing" of the horizon, i.e. in the attempt to harmonize new sensory input with the possibilities that are prescribed by the intentional content.

Perceiving objects always and necessarily means to perceive objects in a particular manner, a manner which is determined by a particular intentional content. And in the majority of extra-scientific cases, these intentional contents can be linguistically expressed by natural language terms such as "bike" or "barn" (Husserl 1973b, sections 81-85). Now, on the interpretation proposed here, Weyl's point is that in scientific cases, too, the intentional directedness essentially depends on intentional contents through which objects and states of affairs are intended in a certain way. Weyl's example of electric fields makes this point vividly: Assume that you are asked to follow an experiment in which an EF-probe is used to measure the strength of the electric field at a particular point between two conductors. In order to make sense of the observable occurrences (i.e. the placement of the probe and the output on the readout-unit) from a scientific point of view, you will need to conceptualize the experimental arrangement through the intentional content

$$\vec{F}(P) = e \cdot \vec{E}(P).$$

Now that you have intended the situation in a manner determined by this intentional content, you have learned to view the situation in a much more sophisticated way. What you are intentionally directed to is no longer a situation in which one piece of electronics reacts to the placement of another piece of electronics. After conceptualizing the experiment through a new intentional content, the perceived situation has a different meaning for you because the intentional content has led you "to conceive of an electric field, mathematically described by the vectorial point function $\vec{E}(P)$" (Weyl 1949, 114).

If the proposed interpretation is correct, one of the central tenets of Weyl's account is that scientific cognition ought to be studied from the viewpoint of a phenomenological theory of intentionality. If, for instance, we seek to understand the role of models in the constitution of scientific reality, they must be construed as intentional contents, i.e. as that which determines a very specific way to be intentionally directed towards objects and states of affairs.[11] However, on the basis of our earlier discussions it is also

[11] To be sure, this does not imply that models are always intentional contents. Looking at the practice of a theoretical physicist who is working on a model, the model is the *object* of intentional directedness and not the content through which other objects and states of affairs are seen. However, this double role

clear that conceptualization is but one accomplishment of intentional contents. Besides conceptualizing objects as such-and-such, intentional contents also awaken horizons of possibilities that govern anticipations concerning further aspects and properties of the intended object. As Weyl's example shows, this is also true in scientific contexts: The intentional content $\vec{F}(P) = e \cdot \vec{E}(P)$ establishes a space of possibilities that regulates how certain properties—in this case the charge of the particle, the field strength and the force experienced by the particle—are thought to be structurally correlated in a law-like manner. Hence, if the situation is conceptualized accordingly, one does not merely perceive a particular experimental configuration as one concrete instance of an "infinite continuum of possibilities" (Weyl 1949, 113). Co-given with the experience of one configuration is also a continuum of possibility-driven anticipations of further configurations and scenarios.

I take it that these remarks make it clear why, on Weyl's view, cases of model-based knowledge acquisition and cases of perceptual experience should be treated as structurally analogous. As has been pointed out, the process of perception consists in the "probing" of the horizon, i.e. in the stepwise attainment of new sensory inputs and the attempt to harmonize the input with the horizon. This is also what happens in Weyl's example: In simple cases of perceptual experience, new sensory input is acquired through the movement of the observer's body. In the case of the electric field, new input is acquired either through the variation of the particle's charge or through the variation of the particle's location. In cases of perceptual experience, the result of the variation of the observer's location is a new two-dimensional appearance of the physical thing. In the case of the electric field, the variation of the particle's charge or location results in a force that is exerted by the field upon the particle. Finally, in cases of perceptual experience, the intended object is a three-dimensional thing that transcends the sensuously given and that is constituted in perspectival appearances and through the horizon within which these appearances are embedded. In Weyl's example, the intended object is an electric field that is constituted in changing forces and through the horizon of possibilities that is awakened by the respective intentional content. Hence, as these remarks show, it is only against the background of Husserl's theory of horizonal intentionality that Weyl's analogy between perceptual perspectivity and the probing of electric fields through test particles indeed becomes "complete" and "obvious".

Let us summarize by returning to the three questions we set out to answer at the beginning of this section. The first question was epistemological in nature: How do cases of model-based knowledge acquisition compare with more mundane cases where knowledge is gained without the use of models? Although, of course, more work is needed to develop a comprehensive phenomenological theory of scientific modeling, a Weylean answer begins with highlighting the similarities between simple perceptual cases and more sophisticated cases of model-based knowledge acquisition. These similarities stem from the fact that every cognitive encounter with the world is achieved by a subject

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of models does not undermine the account defended here: When I perceive an object as a barn, then "barn" is the intentional content through which I perceive the object as such-and-such. But, of course, it is always possible to make the intentional content the object of my intentional directedness, for instance, when I am reflecting on what it means to intend the object as a barn.

that is intentionally directed towards the world through intentional contents. To be sure, as Husserl is at pains to show in the *Crisis*, the intentional contents that are being used in the sciences are categorically distinct from their extra-scientific counterparts, and ignorance of this distinctness harbors the danger of a metaphysical hypostatization of scientific activity (Wiltsche 2016a).[12] However, as Husserl also emphasizes (Husserl 1970, 50-51, 304-314), this does not change the fact that there is continuity between scientific and extra-scientific cases of knowledge acquisition, a continuity that is grounded in the underlying structures of intentionality.

The second question concerns the issue of how the representational capacities of models are brought about. With respect to this question, a Weylean theory agrees with deflationary accounts according to which there is no special problem about scientific representation because "the varied representational vehicles used in science [...] represent their targets [...] by virtue of the mental states of their makers/users" (Callender and Cohen 2006, 15). This is to say that the representational capacities are not due to certain intrinsic features of scientific models; rather, scientific representation is parasitic on the intentionality of conscious acts. Hence, since "all representations have an intentional character, representing for a particular purpose [...] and from a particular set of values, techniques and established practices" (Ryckman 2003, 81), a Weylean theory is also in basic agreement with those who argue that models cannot be studied "without bringing scientific agents and their intentions into the picture" (Giere 2010, 269; van Fraassen 2008).

The third and final question concerns the ontological status of models. Insofar as they are mathematical, scientific models are abstract objects that have an ideal being of their own. This, however, does not commit a Weylean account to a strong counterfactual notion of mind and language according to which abstract objects would also exist if there were no subjects to talk and think about them. Instead of subscribing to such a view, which is clearly at odds with Weyl's and Husserl's idealist leanings, phenomenology adopts an intermediate position between Nominalism and Platonism. On this view, abstract objects are constituted through higher-order cognitive activities such as abstraction, idealization and formalization (Drummond 1984, Tieszen 2010). However, in order for their "ideal objectivity" to be stabilized, abstract entities also essentially depend on processes of "sedimentation" in which their original meaning becomes externalized through the use of symbolic notations (Husserl 1970, 356-357; 1973b, section 67; 1969, 263; Duke and Woelert 2016; Wiltsche forthcoming a). This aspect not only underscores the communal character of modern mathematized science (e.g. Wiltsche forthcoming a). It is also the starting point for Husserl's "archaeological" analyses of Galilean mechanics (Husserl 1970, section 9) and Weyl's critical reformation of general relativity.

[12] An important desideratum of the planned research project could be to contrast Weyl's detailed analyses of the constitution of "scientific reality" with Husserl's later work, specifically with his critical concerns about the relations between "scientific reality" and the "Life-World".

5 Dissemination Plans

The outcome of the planned research project will be disseminated through presentations, journal articles, a journal special issue or anthology and a monograph.

In order to discuss my research with other experts in the field, I am planning to present my work at international conferences such as the biannual *HOPOS* meetings, the conferences of the *European Philosophy of Science Association* or the conferences on *Integrated History and Philosophy of Science*. In August 2017 I have delivered a talk on Weyl's philosophy of science at the *40^th^ International Wittgenstein Symposium* in Kirchberg, Austria. In April 2018 I will present a paper on Weyl at the Conference of the *Society for Philosophy of Science in Practice* in Ghent, Belgium.

Regarding journal articles, I am currently working on a manuscript that deals with Toader's claim that Husserl's and Weyl's notions of objectivity were incompatible and that this incompatibility led to Weyl's alleged turn against phenomenology (Toader 2013). This manuscript will be submitted to *HOPOS*. I am planning to submit further manuscripts to peer-reviewed journals such as *British Journal for Philosophy of Science*, *Studies in History and Philosophy of Science* or *Synthese*. These papers will be the core of a book manuscript that shall be finished at the end of the fourth year of the project. This planned monograph is a crucial step in my academic career because it will also be my Habilitation thesis.

In order to promote the planned research project in the international community, I am currently organizing an international, three-day conference "Phenomenological Approaches to Physics" that will take place at the University of Graz in June 2018.[13] T. Ryckman (Stanford University), S. French (University of Leeds), M. Bitbol (École Normale Supérieure) and H.-J. Rheinberger (Max Planck Institute for the History of Science, Berlin) have accepted my invitation to deliver keynote lectures. All in all, there will be 16 talks from scholars from 10 different countries. I am currently in negotiation with Routledge to publish a selection of papers in the form of an edited volume.

6 Cooperation Arrangements

The planned research project will be affiliated with the working unit "Phenomenology" at the Department for Philosophy at the University of Graz (60%) and with the Center for History of Science at the University of Graz (40%). The working unit "Phenomenology", which is headed by Prof. Sonja Rinofner-Kreidl,[14] one of the leading experts on phenomenology and European Editor of *Husserl Studies*, is home to several Post-Docs, PhD-students and guest researchers who work on phenomenological topics. The Center for History of Science is headed by Prof. Simone De Angelis[15] with whom I am teaching courses on history and philosophy of science. The third important local cooperation is Prof. Axel Maas[16] from the Department for Theoretical Physics with whom I am

[13] More information can be found on www.phenphysics.weebly.com.
[14] https://homepage.uni-graz.at/en/sonja.rinofner/
[15] https://wissenschaftsgeschichte.uni-graz.at/
[16] http://physik.uni-graz.at/~axm/scientists.html

teaching courses on philosophy of physics. The cooperation with De Angelis and Maas is crucial to ensure the quality of the project concerning scientific and historical aspects.

As far as international networking goes, the most important cooperation partner is T. Ryckman. The idea to write this research proposal grew out of a graduate seminar that I taught together with Ryckman during my research stay at Stanford University. Since Ryckman is one of the leading experts on Weyl, it will be crucial for the success of the project to strengthen this cooperation. It is for this reason that I am planning to visit Stanford University for 4 months during the second and the fourth year of the research project. Spending time at Stanford University would also give me the opportunity to discuss the results of the planned research project with other philosophers of science cognizant of Husserl and Weyl, such as, most notably, Michael Friedman.

Additional international cooperation partners are Steven French (University of Leeds), one of the leading philosophers of physics who has published on phenomenological topics (French 2002), Walter Hopp (Boston University), an epistemologist and philosopher of perception who works both in the phenomenological and the analytical tradition, Norman Sieroka (ETH Zurich), an expert in Husserlian phenomenology and Weyl, Michel Bitbol (École Normale Supérieure), who has published extensively on philosophy of physics and phenomenology, Uljana Feest (University of Hannover), a philosopher of science who is also familiar with Husserlian phenomenology, and Dan Zahavi (University of Copenhagen), one of the leading phenomenologists and director of the Center of Subjectivity Research. Letters of support from Ryckman, French and Hopp are enclosed at the end of this research proposal.

7 Human Ressources

I received my PhD at the University of Graz, Austria, in 2008. After two years as a Post-Doc researcher, I have been awarded an Erwin Schrödinger Research Scholarship to continue my research at the University of Toronto (2010-2013). In 2013 I have accepted a non-tenure position (50% enrolment) at the rank of an Assistant Professor at the Department for Philosophy at the University of Graz (2013-2017). In 2015 I have been awarded a Fulbright Scholarship to teach and conduct research at Stanford University (December 2016-May 2017). Since 2013, I am also a lecturer for history and philosophy of science at the Center for History of Science at the University of Graz. Since 2018 I teach graduate seminars on philosophy of physics with Professor Axel Maas from the Department of Theoretical Physics at the University of Graz.

Awarding the FWF stand-alone-project would enable me to have a 100% enrollment until 2022 and to reduce my teaching load. This is essential for having the research capacity to finish a monograph on a Weylean philosophy of science and to gain my Habilitation. Moreover, it would offer me the opportunity to devote my time to research while also being on the job market after my fixed term enrollment as an Assistant Professor.

8 Implications for Other Areas of Research

Although the main focus is on philosophy of science, the outcome of the project is relevant for other areas such as history of physics or history of 20th century philosophy. Besides shedding new light on the infamous analytic/continental-divide, the planned research project is also expected to spark interest in phenomenology among "mainstream" philosophers of science. Moreover, a critical evaluation of Weyl's creative use of Husserlian ideas will give new impulses to current research in phenomenology.

Quite generally, the planned research project is a natural continuation of the interdisciplinary approach I have been promoting at the University of Graz during the last couple of years. I have established working relationships with historians of science, theoretical physicists and philosophers from other areas in order to make an impact both on the level of research and on the level of teaching. Apart from interdisciplinary conferences, workshops and publications, I have designed interdisciplinary seminars for graduate and undergraduate students, such as the research seminar "Philosophy of Physics" that I am teaching with the theoretical physicist Prof. Axel Maas, or regular seminars on "Integrated History and Philosophy of Science" that I am teaching with the historian of science Prof. Simone De Angelis. Awarding the FWF stand-alone-project would enable me to intensify these existing cooperations and make them internationally more visible.

9 Financial Aspects

The planned research project will be carried out at the Department of Philosophy at the University of Graz. The department will supply the project with the infrastructure (office space, library access, etc.), the equipment and material that is necessary for carrying out the project.

Personell Costs:	€290.520
Non-personell Costs:	€30.000
Mandatory 5% of total requested (€320.520):	€16.026
The project's total funding request amounts to:	**€336.546**

Personnel costs for the principal investigator Dr. Harald A. Wiltsche (based on FWF guidelines):

	Salary/year:	Rate:
Year 1	€72.630	100% Senior Post-Doc Position
Year 2	€72.630	100% Senior Post-Doc Position
Year 3	€72.630	100% Senior Post-Doc Position
Year 4	€72.630	100% Senior Post-Doc Position
Total	**€290.520**	

Non-personnel costs:

Year 2	Housing costs for Stanford, CA: €13.000 Travel costs, Graz-San Francisco-Graz: €1000 Travel costs for talks in the US: €1000 Total: €15.000	4 months stay at Stanford University, CA
Year 4	Housing costs for Stanford, CA: €13.000 Travel costs, Graz-San Francisco-Graz: €1000 Travel costs for talks in the US: €1000 Total: €15.000	4 months stay at Stanford University, CA
Total	**€30.000**	

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