Feynman's Diagrams, Pictorial Representations and Styles of Scientific Thinking*·

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Abstract

In this paper we argue that the different positions taken by Dyson and Feynman on Feynman diagrams' representational role depend on different styles of scientific thinking. We begin by criticizing the idea that Feynman Diagrams can be considered to be pictures or depictions of actual physical processes. We then show that the best interpretation of the role they play in quantum field theory and quantum electrodynamics is captured by Hughes' Denotation, Deduction and Interpretation theory of models (DDI), where "models" are to be interpreted as inferential, non-representational devices constructed in given social contexts by the community of physicists.

1. Introduction

The aim of the paper is to discuss the alleged representational role of Feynman's diagrams (FDs) in the context of quantum field theory and in particular in quantum electrodynamics.

Physicists working in particle physics use FDs to calculate the outcomes of interactions between particles. However, it is still debated whether FDs are only a convenient tool to help the calculations or have instead a representational role of some kind. In the latter hypothesis, one could claim, for example, that they are representations of physical processes involving interactions between charged particles. As we will see, however, there are important reasons to resist this interpretation, in particular if in this context we identify "representation" with *pictorial* representation[3]. The problem with this claim is that in the context of quantum field theory and quantum electrodynamics, FDs seem to have

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3 For the notion of representation, see van Frassen (2008).

only a *pragmatic role*. More precisely, while it is true that there is a sense in which FDs help to visualize what is going on during an interaction between charged particles, they do so only in a *heuristic way.* Our conclusion will therefore be that FDs are important tools to simplify the calculations and we will defend this claim by adopting Hughes's theory of scientific *models* (Hughes 1997).

The paper is structured as follows. In the second section, we will briefly illustrate the formalism of FDs and explain why certain of its features can lead to be mistaken belief that they can act as a *pictorial representation* of physical processes occurring in spacetime. We will also stress the aspect of the formalism that instead points toward an instrumentalistic account of the role of FDs. In the third section, we will briefly sketch the main problems encountered by the claim that FDs are a pictorial representation of the physical processes that they might to taken to describe. In the fourth section, we will explain why framing the role of FDs in the context of a theory of scientific models originally proposed by Hughes (1997) seems a very plausible move, and will mention in passing how this interpretation is compatible with another account of models that is defended, for instance, by Suárez (2004) and van Fraassen (2008).

2. Feynman's Diagrams from A to B[4]

In order to pose the problem of the representational power of FDs, we need to sketch in a qualitative, brief but as-precise-as-possible way the role that they have in quantum field theory. One of the purposes of this presentation is to try to figure out whether they can be considered in some sense *laws* that govern the interaction of particles. FDs were originally proposed by Richard Feynman (1949a, 1949b) to describe and calculate processes of interaction and scattering in the specific context of quantum electrodynamics. Quantum electrodynamics is a quantum field theory that describes the fundamental interactions between photons and charged fermions in terms of scattering processes and bound-state problems. As is well known, quantum electrodynamics describes the interactions between two quantized fields: the *electromagnetic field* (the Maxwell field) and the *electron-positron field* (the Dirac field).

In order to consider interactions in the context of quantum field theory, one has to formulate a perturbation theory by splitting the Lagrangian that describes the quantum field in two parts: the *free part*, that refers to non-interacting particles, and the *interaction part*, that refers to interactions. The

4 The title of this section echoes that of Geroch's book *Relativity from A to B*, Chicago, 1978.

formal tool that enables to calculate the interactions starting from an *initial free state* |IN> to a *final free state* |OUT> is the S-matrix. It is important to note that both the initial and final free states are definable only in the limit of time going to infinity. That is, the |IN> and |OUT> state describe the physical world only when $t \rightarrow \pm \infty$. *In evaluating the question that we are after, one ought not to forget the presence of this evident idealization*. The calculation of the S-matrix expansion is often very difficult and the FDs have the fundamental role to make it simpler.

Accordingly, Dyson (1948) considered the FDs as a set of rules associated to the diagrams in order to calculate matrix elements for scattering processes. In the context of quantum electrodynamics, Dyson himself provided a formal derivation of the FDs for an initial (and final) state of a charged particle in a process in which there are no photons: each term in the matrix element can be associated to a *graph* – that is, a FD – such that there is a one to one correspondence between types of matrix elements and graphs (and therefore FDs).

However, Dyson's approach seems prima facie to support also the idea that FDs, in a sense, help the visualization of the physical processes described by the S-matrix. On the basis of the following quotation, one might even conclude that Dyson regarded the FDs "as a picture of the physical processes which give rise to the matrix element" (Dyson 1948, 496). However, in the context of this paper it is difficult to establish whether Dyson's use of the word "picture" was only metaphorical. As a matter of fact, we will see in the following that Dyson in fact believed that FDs were only a convenient formal tool to calculate the expansion of the S-matrix, exactly in virtue of the one to one correspondence between FDs and matrix elements.[5]

In order to make our claim more convincing, we should first of all consider the arguments that may lead one to believe that FDs represent in a pictorial way. To begin with, the FDs are usually *drawn* in a plane, where the horizontal axis represents space and the vertical axis represents time[6]. Moreover, FDs represent fermions with *straight lines* and bosons with *wavy lines*. Additional evidence for the claim that the FDs represent scattering processes pictorially is reinforced by the fact that (i) each fermionic line preserves its spatiotemporal orientation, which represents whether it is at the *origin* of the interaction or its *result* and that (ii) basic interactions are represented by a *vertex*, which is defined as the conjunction of at least three lines. These three lines symbolize two fermionic particles and a

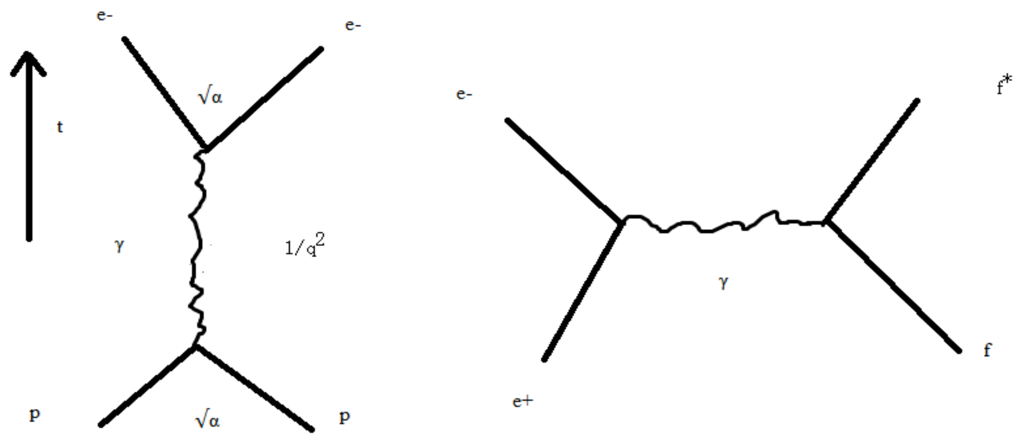
5 In the secondary literature, this algorithmic role of the FDs has been stressed by Kaiser (2000, 61), who claims that FDs are nothing but "conventional representational schemes with no pretentions to picturing actual particles' real scattering".
6 Some physics textbooks prefer the opposite convention, and represent time with the horizontal axis and space with the vertical axis.

bosonic particle, which stands for the *minimal interaction* among the former. To each *vertex*, also suggesting a pictorial image, is associated a *coupling constant* that characterizes the interaction – for example, the electric charge in the context of quantum electrodynamics. At each vertex, the relativistic stress-energy tensor is conserved. Furthermore, also the idea of a coupling constant seems to suggest the claim that in this context one is representing *a law of nature*, while the products of interactions might be regarded as events in spacetime.

2.1. Are Feynman's Diagrams pictures?

However, if one analyses some specific aspects of the physicist's use of FDs, it is possible to show why FDs cannot really be considered as representations of real physical processes in spacetime. In fact, if we assign to the |IN> state different particles, then the same fundamental diagram can represent different physical processes, as it is possible to see in (FIG. 1). It is true that the two FDs have a different spatiotemporal orientation on the plane, but here the point is that the two FDs are *structurally equivalent*. This means that the only difference is a difference in spatiotemporal orientation, that is, the fact that one can be interpreted as the result of the rotation of the other. In any case, if we regard a particular FD as a representation of a certain physical process, it should be different from a FD representing another physical process, independently of its spatiotemporal orientation.

As an example, consider the first FD on the left, which represents a process of diffusion of electrons and protons, while the second FD on the right represents the annihilation of an electron and a positron with the creation of a pair of a fermion and an antifermion. The term $\sqrt{\alpha}$ in the diagram is the coupling constant, the γ is the *propagator* (identifiable with the exchange of a *virtual particle*), $1/q^2$ is the impulse transported by the photon, where q is the charge of the particle. In other words, this case shows how regarding FDs as representations of physical processes in spacetime would imply that different physical processes have the same representation. But since a representation of a physical process should be different from the representation of another physical process, FDs in general cannot be considered as representations of physical processes in spacetime, at least according to this aspect of their use. As we shall see later in this section, this is just one of the problems that a pictorial interpretation of FDs has to face.



(FIG. 1)

It is plausible to assume that the pictorial nature of any representational vehicle depends on the possibility to regard the target as a process that takes place in spacetime. This in turn implies the possibility of *visualizing* this very process thanks to what Kant called the pure a priori forms of our intuition of all possible phenomena, namely space and time. As we will see below, this element of visualizability is very relevant to explain the uncontroversial role played by the FDs in *learning* and in *understanding* the theory (Kaiser 2000). This pedagogical element is very plausibly grounded in the "cognitive structure of the human being", as one could reformulate the above-mentioned principles of Kant's transcendental aesthetic. Such a structure is what led Schrödinger – in the wake of the neo-Kantian tradition of Helmholtz, Boltzmann and Hertz – to claim that what cannot be represented via a *Bild* in spacetime "cannot be understood at all" (quoted in Beller 1997, 427). Of course, after having granted that human beings are basically visual animals – since they extract most of the information on the external world through their eyes –, we should admit that it is one thing to argue that FDs are props to try to figure out what happens in the physical world, quite another to claim that they really represent a spatiotemporal process.

In this respect, the impossibility of regarding FDs as pictures of the physical world has been made to depend on the Heisenberg uncertainty principle and the consequent lack of a well-defined spatiotemporal trajectory (Brown 1996). In addition to this claim, which could be interpretation dependent[7], there are other serious technical reasons forbidding a talk of trajectories of particles in the

7 In Bohmian mechanics, for instance, particles always possess a definite position and velocity.

context of FDs.

In order to appreciate the fact that the FDs are merely bookkeeping devices, we should stress their role in calculating scattering processes within the so-called Feynman's *spacetime approach* to quantum electrodynamics. If we consider an electron-electron scattering process, we will have a virtual photon propagating *all over Minkowski spacetime*, i.e. tracing all the possible paths that connect the first electron to the other electron. This propagation is represented by a time-ordered product in the S-matrix. This virtual photon (Feynman's propagator) is assumed to be *created* at a spacetime point x_1 and to be *annihilated* at a spacetime point x_2. To calculate the S-matrix, one then needs to consider the contribution of all possible localized interactions of the Dirac fermionic and Maxwell bosonic fields, as they are connected by the virtual photon propagator. Technically speaking, one has to integrate over the probability amplitudes of all these possible paths.

Moreover, it must be noted that the interaction that we are now describing results from the contribution of the propagation of the virtual photon from one electron and the other, *and viceversa.* Since FDs can be seen as a representation of a global spatiotemporal description of scattering processes all over Minkowski spacetime, how can this feature be understood as a picture of a real, localized physical process? In other words, "overall" means that we do not have a description of the interaction taking in a local region of spacetime, that is, we do not have an "in space" and "in (through) time" description of the interactions. A process, exactly as a particle, must be contained in a *local* region of spacetime!

As a consequence, it is much more plausible to assume that a FD is just a black box that helps to calculate the complex function from an |IN> to an |OUT> state associated to a certain interaction. Do we have some reasons to resist this instrumentalist conclusion? In order to further confirm our view, we should try to look into the reason that might be taken as evidence for a realistic view.

This point introduces the topic of the next section, namely the *pedagogical* role of the FDs. Kaiser (2000) for one regards FDs as *conventions,* but not chosen at random, since he argues that the way in which they are introduced and explained to physics students relies on a comparison with Minkowski diagrams.[8]

[8] Furthermore, it seems to us that Kaiser's claim that the wrongheaded association of *realism* to FDs in 1950s and 1960s has been suggested by their similarity with the "real" photographs of "real" particles in the bubble chambers is quite plausible.

3. Do Feynman's Diagrams represent (pictorially or otherwise)?

The main problem to face when we ask the question whether and in what sense FDs represent is our lack of understanding of a more general question, namely: What does it mean to claim that a physical theory represent or fails to represent the world? Depending on various philosophical positions on the nature of scientific representations, one gets different answers. And typically, even if we had a widely shared explication of the notion of scientific representation (which we don't), the application of this *general* explication to a *particular* physical theory *T* may end up leaving us with different answers. This difficulty has already been stressed by Walton, when he refers to "the confused profusion of senses and nonsenses" (Walton 1990, 3) in which the term 'representation' is used.

In our case, not only is the issue of the representational power of FDs subject to the vagueness of the concept "scientific representation" but the problem is made even more complicated by the simple remark that FDs *prima facie* are *not* a physical theory of phenomena, in the sense in which, for instance quantum electrodynamics is.

Unfortunately, the way out of this conundrum is not to claim that FDs are *laws* governing the interaction between electrons and photons or more generally, other kinds of interactions, wherever this term applies. On the one hand, as hinted above, scatterings are certainly physical processes taking place in spacetime and coupling constants derive from physical theories. On the other hand, however, the issue whether FDs are bookkeeping devices or something more cannot be resolved by trying to understand the nature of natural laws, since it is always possible to defend a view of lawhood that regards the latter as inference tickets. In order to defend our main instrumentalist claim against recent notable attacks (Meynell 2008) and defend instead Brown's view (1996), we need to specify in a clearer way the conditions under we would be ready to claim that the representational vehicle picks up the target in a pictorial way.

In order to tackle this question, we should first of all give clear cases of pictorial representations, in order to find out whether it is possible to squeeze out a common element. For instance, *preservation of angles* conjoined with scale invariance is a sufficient condition for a vehicle of a representation *V* to be a pictorial representation of the target *T*, as it occurs in the case of maps, photographs and "faithful" hand-made portraits. Also caricatures belong more or less to this category. But are these criteria also necessary? FDs obviously do not satisfy them.

It might be retorted that these criteria are too strong. Clearly, there is a continuous transition between clear cases of pictorial representations and cases in which mere inkblots on a flat surface have no pictorial character whatsoever. Rothko's paintings belong to this latter case, but it seems to us that they would still count, on Meynell's criterion, as a prop for our imagination. Of course, we could *see* Rothko's painting *as* …, but whatever 'we see as' risks being subjective or not intersubjectively shared. We all see the same profile of inkblots on a flat piece of paper, but what matters in Rorschach's tests, for instance, is what one *see as*, and this is why they are used as a test for personality traits. If FDs were like Rorschach's spots, we could not treat them as pictures or depictions, because they must prompt the *same* picture or image to everybody.

Related to this difficulty, we must not forget that there is an important subjective element in *styles of scientific thinking*.[9] Interviewed by the mathematician Jacques Hadamard, some mathematicians and physicists reported that they "rarely think in words at all", but rather take advantage of visual and other kinds of mental images, often pictures. Others, on the contrary, seem to rely on purely symbolic or linguistic ways of thinking. Given what we know about his style of doing science, Dyson belong to the latter type of scientists while Feynman to the former, something that could explain why they held different ideas about how the diagrams should interpreted and used.

Einstein, for one, belonged to the first type of scientist, as he told Max Wertheimer that he never thought in logical symbols or mathematical equations, but in images, (Wertheimer 1959, 213-228). In a letter to Hadamard, he wrote that "[t]he words of the language, as they are written or spoken, do not seem to play any role in my mechanism of thought. The psychical entities which seem to serve as elements in thought are certain signs and more or less clear images which can be 'voluntarily' reproduced and combined. The above mentioned elements are, in my case of *visual* and some of a muscular type. Conventional words or other signs [presumably mathematical ones] have to be sought for laboriously only in a secondary stage, when the associative play already referred to is sufficiently established and can be reproduced at will." (Hadamard 1945, 142-143, italics added).

Rather interesting for us is the fact that Feynman (1997), as he himself tells us in his *Surely you are joking Mr. Feynman?*, thought in pictorial images when, for example, he tried to prove visually a theorem that his colleagues mathematicians had proved in symbolic sequences.

These remarks seem to point toward two different conclusions. The first is that, in general, pictorial images may play a role in inventing a physical theory or a calculation tool (in the context of

[9] We take the notion of style of scientific reasoning from Hacking (1992) even though we use it in a very different, cognitive-oriented way.

discovery), but since their justification lies in something else (theorems for instance, or precise predictions expressed in symbols) these images can only be considered as instrumental to the theory itself. We take this point as uncontroversial. The second is that, as Kaiser has insisted, the act of baptism that led to the discovery of a certain technique in the context of discovery is not forgotten by later scientists, but becomes in some sense a consolidated way to present the theory even in the context of justification.

Since the existence of different styles of thinking about theories is empirically supported by the cognitive sciences and by the reports of physicists, it may well be the case that whether FDs represent or not is a purely subjective matter. Given this subjectivity, however, one cannot claim that FDs represent as pictures, since whether something represents pictorially or not has a normative component and cannot just be a matter of subjectively different cognitive styles of reasoning. And yet, differences in styles of thinking seemed to be present at the very outset of the creation of quantum electrodynamics.

This is confirmed also by the following passage from Kaiser: "From the very beginning, Feynman and Dyson held different ideas about how the diagrams should be drawn, interpreted, and used. For Feynman, doodling simple spacetime pictures preceded any attempts to derive or justify his new calculational scheme. To Dyson, the diagrams could be of any help only if they were first derived rigorously from a specific field-theoretic basis. To Feynman, his new diagrams provided pictures of actual physical processes, and hence added an intuitive dimension beyond furnishing a simple mnemonic calculational device. To Dyson, the drawings were never more than 'graphs on paper', handy for manipulating long expression." (Kaiser 2005, 175–176). As hinted above, the fact that Dyson acknowledged the possibility that FDs could also be used to represent pictorially does not detract from the difference that Kaiser has remarked in this quotation.

It seems to us that Meynell's position is compatible with a purely subjective view of imagination. While such a subjectivity can be appropriate for a painting, given that it need not be a representation *of* something else, namely a picture of something, the case of FDs is fundamentally different: what matters in our case is whether they are pictures *of* something, not that they can be used, either pedagogically or heuristically, as props for our imagination, or make-believe.

Furthermore, consider the following interesting quotation: "depiction differs [from pictures] in that it is through seeing the picture that we imagine ourselves seeing the pictured state of affairs" (Meynell 2008, 50). This means that when we look at a FD, we imagine ourselves seeing the quantum phenomenon we are trying to describe, much in the sense described above by Einstein and Feynman. But if our images are off target, FDs do not depict at all, and neither are they pictures.

If we need a criterion of correctness for our imagination in order to claim that FDs represent as depictions or picture, we must disagree with the following claim: "the question of how and whether particular pictures denote is certainly an important question, but it is a different question to the question about how and whether marks on a surface – say, Feynman diagrams – pictorially represent." It is a different question, but the important question, it seems to us, is the former and not the latter: if by looking at a FD we imagine ourselves seeing a true quantum phenomenon, how can we be sure that we are seeing something out there and not merely hallucinating? Imagination seems too weak a criterion for a pictorial representation in science, so that we are pushed toward a normative criterion that tells us that we are indeed depicting something and note merely imagining something that might not exist. In a word, it is easy to claim that FDs are pictorial representations if denotation of some sort is not taken to be necessary for a "depiction".

Finally a reason to be skeptical about an objective pictorial component of FDs is given by the plausibility of the thesis that pictorial representations, and scientific representations in general, have an intentional component and a conventional element, that draws out attention to the context of use (Callender and Cohen 2006). "I use a picture M with the intention to represent P" is analogous to "I use the black ball that is about to collide with the red ball to represent a scattering of particles", or even, "I use a salt shaker and a plate to represent the Moon orbiting the Earth". This intentional component may well force one to conclude that whether or not FDs are pictures of something or not may depend on the particular use or aim at hand and therefore by the intention of the speaker.

In other words, Meynell's brilliant attempt to separate the question of representation from that of denotation faces some objections. In the case of a physical theory a pictorial representation must be a depiction of something beyond itself. That FDs can be props for a visual imagery is certainly important, but a different and interesting epistemological question, that Meynell does not intend to raise, is the following: is the strength of FDs as calculational device, say, in predicting the magnetic moment of the electron, somewhat dependent on the fact that they are pictures of something?

This question might become a possible argument in favor of a pictorial view of FDs, to the extent that it could exploit the predictive success of quantum electrodynamics by using an inference to the best explanation. In a word, an anti-instrumentalist attitude toward the theory might call into play the pictorial nature of the FDs as the best explanation of the empirical success of the theory, an argument that, as far as we know, the literature has neglected.

4. A model-theoretical, inferentialistic view of representation of Feynman's Diagrams

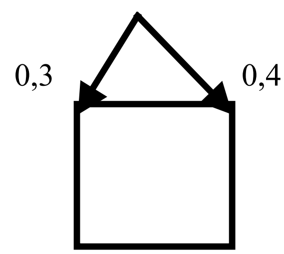
If the notion of pictorial representation cannot be a valid interpretation of the role of FDs in the context of quantum field theory and quantum electrodynamics, we would like to suggest a different perspective, which excludes both the pictorialist and the merely instrumentalist view of FDs. One avenue has been suggested by Mattuck (1967), who has claimed that FDs have a *quasi-physical* nature, since they do not really represent something physical, but neither are they simple mathematical devices. It order to evaluate a position that, like this, tries to suggest a tertium quid, we should try to clarify the nature of the relationship between FDs and physical reality by replacing "scientific representation" or "pictorial representation" with that of "scientific model".

Obviously, even if it were plausible to claim that we understand "model" better than "representation", the question on the nature of scientific models cannot be solved in the present context (see Frigg and Hartmann 2016 for an informed survey). Neither is it possible to claim that there is universally shared position on the nature of scientific models. Our shift of attention on scientific models, however, is justified by the remark that one of the most interesting but neglected questions surrounding the FDs is, as suggested above, why they are so effective in predicting physical phenomena. It is well known that the prediction of the magnetic moment of the electron, if compared with the experimental data, is possibly the most precise every obtained in the history of physics. If this is the problem on which future research on FDs should concentrate, we suggest that the relationship between the mathematical model and the data model might prove crucial. The problem whether FDs can be regarded as mathematical models of experimental data would pose the issue of their relationship with the physical world under a different light. In this perspective, the main questions raised above would be translated into the following one: if FDs were treated as mathematical models, in what sense could they refer to the physical world?

In general, we should first of all note that models, like representations, are essentially perspectival, in the sense that they always portray the world from some angle, that is, by considering only some aspect of the target to be represented (see van Fraassen 2008, in particular chapter 3). Therefore, one could very plausibly claim that many if not all of the various accounts of scientific models are correct in different contexts, that is, when referred to different physical theories. Consequently there is no question of which is *the* correct theory of models.

However, the predictive, algorithmic component of the FDs as illustrated above seems to calls for some sort of *denotation, deduction and interpretation* model of the phenomena, of the kind defended by Hughes (DDI's model). Denotation might be interpreted as the |IN> state, the deduction part corresponds the algorithm used to calculate the element of the S matrix, and the FDs'|OUT> state is Hughes' denotation stage.

The following example is a good illustration of our claim, and is taken from Feynman's celebrated, popular book on QED, where he explains the conceptual roots of his approach to quantum field theory, essentially involving a sum over all amplitudes (1985, 26) (FIG. 2) (see also section 2 above.)



(FIG. 2)

Let the arrows denoted by 0.3 and 0.4 be the probabilities of a particular process (their amplitude). This corresponds to the process that Hughes calls *denotation*, the first step of his three-fold theory, which in our view implies *embedding a property of the physical system in a mathematical model*.

The second step is inferential and deductive, since it consists in calculating the length of the diagonal and then squaring the number. This is the process that Hughes calls *deduction*, which is *epistemically* crucial in that it allows us to reason *via* the vehicle by using it as a "surrogate" for the actual physical systems (see also Suárez 2004). The mathematics used in this second step increases our information about the original system (Azzouni 2004) but, as claimed above, is devoid of realistic components. In Hughes words: "from the behavior of the model we can draw hypothetical conclusions about the world over and above the data we started with" (Hughes 1997, S331). The final step, which in a sense is the converse of the first, is *interpreting* the obtained result (0,5) as the probability of the event we are interested in: this step transforms the hypothetical information into something that can be subject to confirmation or disconfirmation. If we summarize the main points featuring in Hughes' view of models, we easily realize that a representation relation between mathematical/theoretical model and data model seems to be implicitly invoked in the first and third of the following steps:

1 Represent certain mathematized physical events (data model) with arrows via embedding them in a mathematical model, i.e., *Representation → Denotation by a mathematical model,*
2 Make the relevant calculations by summing the arrows in the appropriate way → *Deduction via FDs,*
3 Regard the square of the diagonal of the arrows as the probability of the data/event we are interested in → *Interpretation of the end product of the calculation*, namely the |OUT>.

Two remarks are appropriate at this point. First, the conventional elements in the DDI model play an important role, since the choice of denoting a certain physical property by a certain component of a mathematical model (embedding) is dictated by reasons of convenience and tractability of the calculations. Second, the DDI model functions in many scientific applications and, we argue, is very appropriate not only to describe the role played by FDs in the physicists' practice, but also how they ought to be regarded by philosophers of physics.

One might want to put forward the point that the assumption that scattering processes are somehow correctly denoted – in Hughes' sense – by the relevant FDs is the best explanation for their predictive success. This might be taken to imply that such diagrams model or denote, in some non-pictorial but robust, structuralist way (Da Costa and French's 2003),[10] concrete physical processes. In order to cast some doubts on realistic arguments of this sort, first of all we should notice that the FDs are not necessary to calculate the scattering of particles: *without* presupposing them, one can still calculate the scattering of the two particles *via* the integral of the particles; so in this case any sort of indispensability argument Consequently, the empirical success of FDs cannot be explained by an inference to the best explanation involving their pictorial, structuralist or similarity-based (Giere 1988) features. In fact, the diagrams, as other bits of applied mathematics, in our case have been devised with the specific aim of calculating more exactly the magnetic moment of the electron and in general the interactions between matter and light: no wonder that they are so successful! Inferences appealing to the fact that many mathematical models of theoretical physics are successful in order to argue that all

[10] These authors do not use FDs to illustrate thei structuralist view of representation.

successful models (Feynman's included) "depict" reality in a unique way – so that a uniquely describable representation relation stands out – are not convincing, because the algorithmic power of FDs may be completely independent of the real processes whose end result they enable us to calculate.

In order to add some pragmatic component to our claim, we conclude by mentioning Suárez's inferentialist account of models (2004), which is not specifically referred to FDs. His position, which is similar to Hughes', focuses more specifically on the community of speakers that use a model in order (i) to grasp the physical process that they are describing and (ii) communicate their analysis in the clearest possible way. According to Suárez, a model is in fact mainly an instrument that lets cognitively informed agents draw inferences about the target, but its denoting and interpretive component is highly contextual

If sum, the best interpretation of the role of FDs in quantum field theory and quantum electrodynamics is captured by an account of their use *via* Hughes' DDI theory of models, where "models" are interpreted as inferential, non-representational devices constructed in given contexts by the particle physics community.

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