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Ontological Investigations in the Quantum Domain: A deflationary approach on ontology of physics

Florianópolis
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For Décio Krause.

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“Grammar tells us what kind of object anything is.”
WITTGENSTEIN, Philosophical Investigations

RESUMO

O objetivo desta tese é propor uma abordagem deflacionária com respeito à análise ontológica de teorias físicas. Essa abordagem defende que o desenvolvimento de ontologias para teorias físicas precisa ser neutro em relação ao debate entre realistas e anti-realistas em física. Principalmente, nossa atenção será direcionada para o que chamamos de “domínio quântico”, que inclui a Mecânica Quântica não-relativística e variantes da Teoria Quântica de Campos. Essa abordagem meta-ontológica intenta fornecer uma metodologia para o desenvolvimento de ontologias para as teorias físicas. Com esse objetivo, sugerimos a separação entre *fenômenos físicos e teorias físicas*, por um lado, e *teorias físicas e ontologias*, por outro. Essa separação visa sustentar a ideia que as teorias físicas podem fornecer todo o conteúdo informativo necessário para a constituição das ontologias associadas a elas. A partir disso, defende-se que as teorias físicas podem contribuir positivamente para a constituição desses modelos ontológicos. Além disso, apresentamos uma análise crítica de quatro interpretações ontológicas distintas para a MQ e a TQC. Cada uma dessas interpretações se baseia em uma categoria ontológica diferente (tropos, eventos e processos). Ao final, sugerimos as linhas gerais que devem antecipar o desenvolvimento dessas ontologias, de acordo com as estruturas matemáticas consideradas dentro das teorias próprias físicas.

Palavras-chave: Meta-ontologia; Abordagem deflacionária; Teoria Quântica de Campos; Mecânica Quântica não-Relativística; Ontologia.

RESUMO EXPANDIDO

Introdução

A presente tese parte da eminente dificuldade de se estabelecer ontologias para teorias físicas. Com este fim propomos uma abordagem deflacionária ao problema da subdeterminação das ontologias pelas teorias físicas. Este método consiste na negação de haja alguma transitividade na tríade fenômenos físicos – teorias físicas – ontologias. Tal negação consiste na afirmativa de que ontologias (vistas aqui como modelos ontológicos informais) para as teorias físicas devem se ater apenas às teorias, negando, assim, uma possível transitividade entre fenômenos físicos e ontologias por meio das teorias. Desta forma, o problema acerca da realidade ou irrealidade dos fenômenos e entidades descritos pelas teorias físicas deixaria de ser uma influência para a constituição de tais modelos ontológicos.

Por isso chamamos essa abordagem de deflacionária, pois o debate entre realistas e antirrealistas em ciência seria posto de lado na constituição das ontologias. Veja que não se trata de negar o debate, mas sim de redefinir a forma como ontologias são construídas. Afinal, o debate sobre a realidade ou irrealidade dos fenômenos e entidades da física é legítima e justificada, contudo, com a abordagem sugerida aqui, acabamos por realocar o debate para o seu devido lugar, a saber, na relação entre fenômenos físicos e teorias e não na suposição de que ontologias usariam as teorias físicas como um *medium* para a descrição ontológico-categorial de fenômenos.

Objetivos

Com a intenção de ressignificar a tríade mencionada acima, realizamos a distinção entre o que cabe à subdeterminação metafísica e o que cabe ao critério quineano de compromisso ontológico. Enquanto o primeiro estabelece uma relação que vai das teorias para as ontologias, o segundo se baseia em uma relação que reafirma o lugar da primeira subdeterminação, aquela que vai dos fenômenos para as teorias.

Com isso tudo buscamos definir a relação entre teorias físicas e modelos ontológicos como a única relação a ser mantida na definição das ontologias. Assim internalizamos as ontologias associadas às teorias físicas nas próprias teorias. Com isso fazemos um movimento análogo ao de Kant ao internalizar a ontologia na epistemologia, só que aqui internalizamos as ontologias nas teorias físicas. Desse modo, as ontologias operam na descrição das entidades segundo o que é definido nas teorias, sendo incontornável a relevância que as estruturas matemáticas, presentes nas teorias físicas, tem nessa definição. Ao longo da tese demonstramos como é impossível realizar uma análise ontológica concisa das teorias físicas sem recorrer aos aspectos matemáticos que *condicionam* a representação das entidades na teoria.

Metodologia

Com o fim de ressaltar como as estruturas possibilitam a representação das entidades nas teorias, oferecemos diversos exemplos ao longo do trabalho. Desse modo escolhemos teorias físicas que podem ser subentendidas sob o rótulo de “teorias quânticas”, justificando assim a ideia de que as presentes investigações se projetam sobre um domínio quântico. Escolhemos assim privilegiar algumas variantes da Teoria Quântica de Campos. Incluímos também exemplos oriundos das Mecânica Quântica não-Relativística.

A tese está estruturada em quatro capítulos principais e uma conclusão, a qual inclui os indicativos metodológicos pressupostos pelo método deflacionário sugerido aqui. O primeiro capítulo trata da descrição detalhada do método deflacionário, suas mo-

tivações e desdobramentos. Neste capítulo definimos o referido método como uma meta-meta-ontologia para a ontologia da física. Com isso realocamos o sentido dos termos “metafísica”, “ontologia” e “modelos ontológicos”. Destes três, apenas o terceiro é tomado como ontologia enquanto proposta meta-conceitual para análise das teorias físicas. O termo ontologia é tomado em sentido meta-ontológico, sendo concebido no sentido de ontologia formal empregada na análise comparativa entre ontologias. Por último, o termo metafísica é concebido como estudo comparativo de diferentes propostas para a solução do debate realismo/antirrealismo. Assim, o método deflacionário é entendido como meta-meta ontologia, pois ele insere a cisão entre ontologia e metafísica com o fim de preservar as ontologias de influências tácitas do dualismo realismo/antirrealismo. Perceba como a abordagem deflacionária preserva a noção de metafísica, sem se imiscuir no debate realismo/antirrealismo.

Resultados e discussão

Os resultados principais da tese são: i) um novo método para o desenvolvimento de ontologias em ontologia da física; ii) uma releitura da relação entre ontologia, teorias físicas e fenômenos; iii) uma possível releitura da relação entre subdeterminação metafísica e compromisso ontológico. No capítulo 2 percorremos diferentes métodos ou abordagens ao problema da definição das ontologias, tais métodos são contratados com casos do domínio quântico que se chocam contra pressuposições tradicionais. Tais métodos são retirados de diferentes fontes e representam boa parte das estratégias possíveis em ontologia da física. Adicionalmente sugerimos o abandono da pressuposição de que interpretações em Mecânica Quântica não-relativística posem ser lidas como modelos ontológicos para a teoria. Na verdade, tais interpretações seriam apenas formalismo usuais para a teoria. Ao final desse capítulo realizamos uma breve análise do conceito de substância e como este pode ser concebido a partir do caso quântico.

Nos capítulos 3 e 4 realizamos a análise de uma ontologia orientada para a Mecânica Quântica não-relativística e três ontologias sugeridas na análise da Teoria Quântica de Campos. Como cada uma dessas ontologias está centrada em uma categoria diferente (tropos, eventos, processos), conseguimos verificar diversos aspectos que podem ser inseridos ou evitados na constituição de modelos ontológicos. Inicialmente, no capítulo 3, analisamos a ontologia de tropos nucleares formulada por Peter Simons para lidar com o problema da superposição em MQ. Em seguida, analisamos a ontologia de tropos disposicionais desenvolvida por Meinard Kuhlmann para a formulação Algébrica da Teoria Quântica de Campos. No capítulo 4 analisamos a proposta de Sunny Auyang para uma ontologia de eventos associada à formulação via fibrados para a Teoria Quântica de Campos. Por último, examinamos a ontologia de processos livre de Johanna Seibt, tal abordagem é pressupostamente orientada para a formulação via espaços de Fock para a Teoria Quântica de Campos. Os resultados endossam a tese de que ontologias para teorias físicas devem se ater preponderantemente às estruturas matemáticas nas teorias e que modelos ontológicos mono-categoriais tendem a perder muitos dos traços essenciais ao estabelecimento de ontologias para as teorias físicas. No capítulo 5, *conclusão*, além dos resultados obtidos, sugerimos as linhas metodológicas gerais que uma ontologia aplicada à Teoria Quântica de Campos deve seguir. Essa linha define que apesar das ontologias fornecerem todo o aparato conceitual necessário para a constituição das ontologias, as ontologias devem se engajar em duas etapas da constituição das categorias ontológicas. A primeira trata da determinação estrutural fornecida pelas teorias. A segunda trata da constituição das categorias apropriadas.

Considerações Finais
Ao final, a tese chega à vários resultados. O principal deles é que o método deflacionário leva ao resultado de que as teorias físicas podem, de fato, contribuir para a definição das categorias ontológicas nos modelos ontológicos e que esse processo não depende de pressuposições realistas ou não sobre as teorias ou os fenômenos.

Palavras-chave: Meta-ontologia; Abordagem deflacionária; Teoria Quântica de Campos; Mecânica Quântica não-Relativística; Ontologia.

ABSTRACT

The aim of this thesis is to propose a deflationary approach towards the ontological analysis of physical theories. Such an approach sustains that the development of ontologies for physical theories must be neutral relatively to the debate between realists and anti-realists in philosophy of physics. Mainly, our attention will be oriented towards what we called “quantum domain”, which includes the non-relativistic Quantum Mechanics and variants of the Quantum Field Theory. This meta-ontological approach consists in an attempt to provide a methodology for the development of specific ontologies for physical theories. With this aim we suggest the separation between *physical phenomena and physical theories* on one side, and *physical theories and ontologies* on the other side. This separation intends to endorse the idea that physical theories can provide all the informative contents required for the development of the ontologies associated with them. The result is a defense of the idea that physical theories can positively contribute for the constitution of the ontologies in physics. Additionally, we present a critical analysis of four different ontological approaches to QM and QFT. Each one of these interpretations deals with a different ontological category (tropes, events and processes). At the end of the thesis we will analyze the concepts of interaction and commutation in QFT in order to exemplify the main lines of the deflationary approach suggested here.

Key-words: Meta-ontology; Deflationary approach; Quantum Field Theory; Non-relativistic Quantum Mechanics; Ontology.

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LIST OF ABBREVIATIONS AND ACRONYMS

AQFT	Algebraic Quantum Field Theory
AxioQFT	Axiomatic Quantum Field Theory
CFT	Classical Field Theory
HQET	Heavy Quark Effective Theory
MU	Metaphysical Underdetermination
MWI	Many-worlds interpretation
OC	Ontological Commitment
PTO	Phenomena-Theory-Ontology
QFT	Quantum Field Theory
QM	Quantum Mechanics
RQM	Relativistic Quantum Mechanics
SR	Special Relativity
TQFT	Topological Quantum Field Theory

CONTENTS

INTRODUCTION

0.1 *STATUS QUAESTIONIS*

There is a clear and prevailing problem in ontology of physics[2] that can be summarized by the following question: *What are the more adequate ontologies in order to describe some given[3] physical theory?*. At first sight, it seems a well-placed question, however it hides serious difficulties for the philosopher. The question above leaves us with the impression that there is a plethora of ontologies at our disposal, and that all one needs to do is just to choose one of them as the preferable one. However, it would be to assume a too optimistic view about the real state of the question. The issue is that the aforementioned question leaves room not only for an undefined number of possible ontologies, but, also, there is no initial restrictions on their limitations and scope after all. In this regard, some kind of a filter should be used to define some limits, and, moreover, to help to characterize which ontologies might fit in the description of a physical theories and which might not. This way, it seems that we should take the question seriously in order to make any ontological approach on the domain of physics.

In this respect, the problem of selecting, identifying, or even creating the "[...] best [...]" (COCCHIARELLA, 2007, p. xiii) ontologies becomes the main line of our investigations. Thus, for me the question above could be replaced by another one: *What are the criteria that one should consider in defining the possible ontologies for the description of a physical theory?* Basically, this thesis focus on this question and its possible ramifications. Therefore, our investigations deal mainly with the problems concerning the methodological steps that could lead to the ontologies; their identification and filtering. To some extent, as I will state in chapter 1, by methodology I mean a deflationary approach in ontology of physics. More specifically, such an approach is not only a methodological suggestion, but a meta-meta-ontological effort to provide a solid base from which we could build ontologies (ontological models[4]) for the physical theories. Accordingly, to define what I mean by a deflationary approach depends on the definitions of external meta-ontology and internal meta-ontology, and, before that, on the definitions of metaphysics and ontologies. The use and extension of these concepts

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[2] See Section 1.2.

[3] In this thesis I do not provide any definition for what a physical theory is or could be. I am generally assuming by a physical theory what the physicist assumes it to be. Certainly, there are serious problems in saying that. For instance, although being considered a physical theory, the Quantum Field Theory does not fit in the habitual surmise that a theory should be a well contained body of rules and methods, all they working harmoniously together. Thus, albeit a matter of high importance, unfortunately we will not deal with such a problem here. See Appendix C, Section A.2. For a discussion see (SUPPES, 1967), (HALVORSON, 2012)

[4] Here and there the terms "ontological models", "material ontologies" and "ontologies", this last one in plural, will be conceived as having the same meaning. Occasionally, the term "ontologies" may acquire other meanings, however the context will make it clear.

are defined in chapter 1[5].

The question of how to define an ontology for some physical theory has gained a new boost in the last thirty years. Different parties have alternated at the forefront of the debate; labels such as “epistemological realism” (WORRALL, 1989) and “structural realism” (FRENCH; LADYMAN, 2010) have emerged and restated the realist debate about the relation between physico-mathematical[6] structures and reality. After all, even though providing major clarifications about the relevance of the mathematical structures in defining the ontologies, both parties have reinforced the role of the realist debate. Hence, with the intention of justifying or denying their realist or anti-realist assumptions both parties have resorted to the candidate ontologies mainly as a means to validate those metaphysical assumptions, thereby denying an autonomous status for the ontologies as “models” for physical theories.

Having said all that, the approach suggested here seeks to show how it is possible to deal with the problem of defining ontologies for physical theories without falling into the traditional dispute between realism and anti-realism. The main idea is to escape from the debate in order to set up ontologies free from tacit presuppositions of classical metaphysics. Clearly, I am not saying that those tacit presuppositions (e.g. substance theory) cannot be considered in the making ontologies; it is still possible to defend a correspondentist approach in contrast with our deflationary approach. But, as I advocate, that is a path that the philosopher might avoid, and more than that, the new path suggested here is more aligned with the conception that ontologies must be in accordance with the physical theories. In this regard, the deflationary approach is two-folded. On one hand, it seeks to escape the endless dispute between realism and anti-realism. On the other hand, by setting aside that dichotomy, the ontologies associated with a physical theory can be generated without the influence of elements that are not present in the relation between physical theories and ontology.

Now, let us see how a deflationary approach can provide a simpler approach to ontology of physics. But, before that, I would like to mention the motivations for the present proposal and why I have chosen the term “deflationary” to denote the approach at stake here.

Roughly, in truth theory a deflationary approach is a theory that assumes that the predicate “truth” is not a real predicate; and, therefore, it is not necessary for the deflationist to be committed with the reality or non-reality of that concept. In this sense, the deflationism is presupposed to remain independent of the dispute between realists and anti-realists. Here, I make an analogous move by assuming the traditional dispute

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[5] See Table 2.

[6] By “physico-mathematical structures” I mean those structures without which a physical theory becomes impracticable for the physicist. For example, in standard QFT the structure of spacetime defined in the standard Special Relativity. Hereafter the terms “physico-mathematical structures” and “mathematical structures” will be understood as meaning the same.

between realism and anti-realism as avoidable for the formulation of ontologies for physical theories[7]. However, even if we do not endorse the debate about realism and anti-realism, I do not deny its relevance. Here, I am just assuming the hypothesis that the debate realism/anti-realism may be read as independent from the problem of defining the best ontologies for a physical theory. As I intend to illustrate the dispute between realism and anti-realism do more harm than good to the ontologist's efforts in ontology of physics.

Notice that we are not saying that there are no philosophical presuppositions of all kinds in general science[8]. Anyway, they exist and make part of the scientist's daily life. As pointed out by Kuhn and Feyerabend, there are many extra-scientific elements that define the scientific activity itself. However, our investigations are far away from sociological aspects that science could embrace. Finally, we aim to remain as neutral as possible in order to avoid explicit or implicit ontological presuppositions that might "contaminate" or "extrapolate" a concise ontological analysis. All in all, the limit of an ontology for a physical theory should be the limit of the domain of the theory.

Now, the crucial point to be observed in these investigations is the fact that we are taking the theories in terms of their mathematical structures. The purpose of this choice is not to celebrate any structuralist approach, but understand the structures that would make possible to give rise to ontologies. In this sense, the present investigations internalize the ontologies in the theories. Mainly I can say that this approach is not new. For instance, in Kant's ontology the categories (of thought) are restricted and internalized in the epistemology. Thus, the Aristotelian ontology that speaks of the world and how things are, becomes for Kant an ontology that speaks of the world according to what is possible to know about it, and not about a world that could be independent of us (KANT, 2010, A247/B304). Namely, Kant internalizes the ontology in the epistemology. For us the case is not so different. If we intend to employ some ontological framework to the physical theories then it is reasonable to assume that such a framework is restricted to the very conditions of possibility of the theories, so to speak, the structural limits imposed by the theories. Properly, we are not saying that an ontology for a physical theory is part of that theory, but that an ontology for a physical theory must be defined by the structural features of the theory itself. At this point, we could paraphrase Kant and ask: What are the *conditions of possibility* of the entities of a given physical theory? Well, whereas Kant is looking for the structures of knowledge, we are looking here for the structures of the theories. To understand how physical theories make possible the representation and, in a certain way, creation of

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[7] Clearly, it is just an analogy. We do not intend to make any analysis about the concept of truth or the possible repercussions that such a concept could have on the matters discussed here.

[8] "Physicist do understand the quantum realm to a significant extent. Their understanding is manifested in the successful application of quantum theories to real-world problems. However, it is poorly articulated. The actions of physicists tacitly uphold a world of view rooted in practice and robust common sense". (AUYANG, 1995, p. 4).

the entities investigated by them, is the most effective way to generate ontologies.

Again, there are two main developments of the approach suggested here:

i) the suspension of any realist or anti-realist assumption;

ii) and the decision to appeal only to the physico-mathematical structures[9].

The second point (ii) relies on the fact that the entities in a physical theory are, directly or indirectly, built upon the mathematical structures; even the experimental success is based on those structures. For instance, each one of the ten transformations in Poincaré Group is linked with the possible arrangements in which a device can be calibrated[10]. For this reason, we are not interested in questioning the theories themselves or how they can be empirically connected with the physical phenomena[11]. "Physics is based on the fact that one can repeat an experiment at different places and at different times. Such a situation is called a symmetry" (BORCHERS, 1996, p. 5).

Obviously, it is not a situation where one can just to ignore the traditional view about ontology, or even to try to generate ontologies from scratch by creating supposedly new and neutral ontological categories. After all, absolute neutrality does not exist, and it would be naive to want to propose a "new" or a "true" ontology after all. The aim of this thesis is not to provide new ontologies, but, above all, suggest a different path for the ontologist interested by the connection between ontology and physical theories. However, this does not exclude the possibility of appealing to a conceptual tradition already established in order to obtain categories that could fit in some ontological description. In that sense, we cannot ignore a certain conceptual sedimentation that is present in both physics and philosophy. This way it is important to distinguish between ontology and "ideology" (SCHAFFER, 2009, p. 348). Notice, that we do not intend to perform here an exercise of hermeneutics *à la* Heidegger by trying to unveil some implicit historical-conceptual inheritance. We only want to point out that if we want to develop a concise ontological investigation then we must examine whether the ontologies are committed with tacit concepts from traditional metaphysics. "Most contemporary ontologists do not even appear to be aware of the fact that they operate within the confines of a longstanding research paradigm which powerfully restricts the space of solution strategies in ontology." (SEIBT, 2002, p. 53)

In this sense, physics and ontology have a very strong conceptual sedimentation as a common characteristic; and being aware of this fact is an essential step in our

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[9] Mainly, I will not consider the distinction between good and bad structures by means of the differentiation inserted by the use of the concept of *surplus structures*. As pointed out by (FRENCH, 2014, p. 30-31), structures before considered as surplus structures can later become representative in the theories. The case of the negative energy solutions for Dirac's equation illustrates how an apparent undesired result can be reinterpreted as representing something new in the theory; positrons.

[10] See (GOMES, 2015, p. 101).

[11] See (SUPPES, 1969, p. 260-261).

investigations. Thus, in ontology as well as in physics the concepts used by both have a sedimented tradition. However, the concepts in physics have a renewed meaning[12], whereas in philosophy this seems to happen much more slowly.

Last but not least, I shall make an exam of different methods used in ontology in general. In order to contrast and analyze those methods I will employ examples of the quantum[13] domain. By quantum domain we denote three different theories: Non-relativistic Quantum Mechanics (QM), Relativistic Quantum Mechanics (RQM) and Quantum Field Theory (QFT). Additionally, I will analyze four different ontological approaches (Simons, Kuhlmann, Auyang, Seibt) towards the quantum domain. All these approaches are attempts to provide an ontological description for QFT. Finally, I will suggest the main lines to the development of ontologies for physical theories by analysing two specific cases (interaction and commutation) in standard QFT.

0.1.1 Justification

The relevance of the research presented here relies on the fact that there are few works on the relation between quantum theories and ontology with focus on meta-ontology. To the best of my knowledge, in light of the problem of creating a methodology for the definition of the ontologies in this domain, the present thesis is the first to make a comparative study of all approaches examined here.

Furthermore, this thesis presents a new methodology which is non reductive to any methodology offered by the main contenders in the dispute between realism and anti-realism in science. Thus, the deflationary approach suggested here has the flexibility to provide a clear path for new ontologies without being committed with any ontological assumptions than those originated from the physical theories themselves.

The approach suggested here is updated and clearly inserted in the nowadays debate about setting up of ontologies for physical theories.

Additionally, in Brazil there is no other work contemplating all the aspects here examined with the direct confrontation with the physical theories.

After all, the present thesis aims to innovate by discussing the problem of defining a methodology for the generation of new ontologies for physical theories without committing itself with the debate realism-antirealism.

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[12] A clear example of this situation is the change in meaning of the concept of mass. From Classical Dynamics to Special Relativity the concept of mass has received several modifications, going from mass to mass-energy “equivalence”. After all, such an “equivalence” is just a “relation” since mass and energy are both conserved quantities and cannot be “transformed” one into other. See (JAMMER, 1997, pp. 86-89).

[13] Hereinafter I use generic concepts from philosophy and physics such as “type”, “object”, “models”, “interpretation”, “quantum theories”, etc.. Also, concepts such as “physical theories”, “ontological categories” are occasionally abbreviated by “theory” and “category”, whose meaning must not be confused with terms like “formal theory” from logic or with terms like “categories” from category theory. Generally, the meaning of these terms will become clear accordingly to the context.

0.1.2 Main Results

The main results of the thesis are:

i) a new view about the relation between physical theories and ontology called "deflationary approach" (Chapter 1);

ii) a criticism of the negative role of the dichotomy realism/anti-realism for the construction of ontologies for physical theories (Chapter 1);

iii) a new analysis of the triad *physical phenomena - physical theories - ontologies* based on the thesis of metaphysical underdetermination (Chapter 1);

iv) a specific analysis of the concept of substance and its uses as an ontological category in ontology of physics;

v) a critique of several methods used in meta-ontology in general (Chapter 2);

vi) a comparative analysis of four distinct ontologies in QM and QFT (Chapters 3 and 4);

vii) a general method for the generation of ontologies in physics (Conclusion).

0.1.3 Main structure

The thesis is allocated in four main chapters and a conclusion.

In *Chapter One* I present the meta-meta-ontological approach called here "deflationary". In this chapter, I defend the view that the formulations of ontologies for physical theories does not need to be committed with assumptions from the dichotomy realism/anti-realism in physics.

In *Chapter Two* I made an examination of several meta-ontological approaches that contemplate the problem of build up ontologies. At the end of the chapter I make an analysis of the concept of substance in the light of several examples from the quantum domain.

In *Chapter Three* I deal with the trope category and its employment in ontology of physics. Particularly, I examine two different ontologies. On one hand, I examine Peter Simons's nuclear bundle trope theory applied in QM. On other hand, I analyze Meinard Kuhlmann's proposal for a theory of dispositional tropes in Algebraic Quantum Field Theory (AQFT).

In *Chapter Four* I present another two different ontologies. First I present Sunny Auyang's proposal of an ontology of events completely based on the mathematical structures underlying QFT. Second I analyze Johanna Seibt's ontology. Her approach is based on an elaborate ontology of process, however her proposal lacks of a solid connection between ontology and theory.

In the *Conclusion* I summarize the main results of the thesis. In addition, I trace the main lines for the development of ontologies based on physical theories.

At the end of the thesis three appendices were added. These appendices contain several elements for the comprehension of many contents of the thesis. Often, I will make references to them in order to corroborate several statements made through the thesis.

1 A DEFLATIONARY APPROACH ON ONTOLOGY OF PHYSICS

> *"[. . .] try to take science on its own terms,*
> *and try not to read things into science."*
> *Fine, A. "And not anti-realism either", p. 62.*

1.1 STRUCTURE OF THE CHAPTER

In this chapter I describe what I mean by a *deflationary approach* on ontology of physics. The understanding of such an approach relies on the clear definition of what I mean by *ontology*, *metaphysics* and *meta-ontology* (external and internal). Actually, the deflationary approach suggested here presupposes intermediary levels of meta-ontological analysis, making it a meta-meta-ontological approach. This approach seeks to reveal that there is a widespread *categorial error* in the ontological examination of physical theories. The origin of this categorial error is both conceptual and methodological.

As conceived here, the main task of the deflationary approach is to divide the triad *phenomena-theory-ontology* Phenomena-Theory-Ontology (PTO) into two dissociated areas of investigations, one *external* and one *internal*. The former deals with the relation between physical phenomena and physical theories, whereas the latter deals with the relation between physical theories and ontological models. I have made such distinction because, as I see it, the claim that ontology must say something about the physical phenomena is always misleading. In my opinion, there is no direct or indirect relation between ontologies, as models for physical theories, and the phenomena examined by those theories. Actually, if there are ontological frameworks that tries to connect ontology to phenomena, it is the result of a long-standing categorial error based on the assumption that physical theories are a *medium* for the ontological examination of the physical phenomena. Additionally, I present the broad view (Table 2) that outlines the general idea around the deflationary approach proposed here. Such a framework includes a brief analysis of our two-folded concept of meta-ontology, which is divided here into *internal* and *external* meta-ontologies.

I also introduce the method of *categorial analysis* that endows the investigation with the conceptual framework to be used in describing and comparing the *ontological categories* (meta-concepts)[1] that are allocated into different ontologies applied to the quantum domain. In addition, I have made a brief comparison of several meta-ontological strategies, which goes from tailoring procedures (FRENCH, 2010) until the examination of metaphysical equivalence (BENOVSKY, 2016) between ontologies.

My main claim is that the physical theories must be a limit for the ontological examination and not a *medium* through which the ontological examination of the physical

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[1] See (GRANGER, 1994, p. 165).

phenomena could be carried out. When one puts both theories and phenomena at the same level and try to build ontologies based in such view, then a confusion between *domain of discourse* (theory) and *domain of reference* (phenomena) arises. This misunderstanding has led to a repeated categorial error. Notice, that I am not denying that the study of physical phenomena have a great relevance in philosophy of science. However, the philosophical (metaphysical) examination of the reality or non-reality of the physical phenomena described by a physical theory is different from the (ontological) analysis of the concepts used by the same theory to represent those phenomena. That is why I advocate that the analysis of the physical phenomena, usually associated with the dispute between realists and anti-relists, is different from the ontological analysis of the theories themselves. In this sense, I denote the study of the specific ontologies (ontological models/material ontologies) for physical theories by the name of "ontology" and the exam of the dispute between realist and anti-realists by "metaphysics".

After all, an ontology (ontological model) about a physical theory is only about the theory and not about the phenomena. It does not matter whether the concepts in a physical theory are referring to something real or not. In the sense defended here, the ontologies are not about metaphysical questions of that sort; they are about the theories as already given to the examination.

If we could summarize what was said above, it could be condensed by the following quote. "Grammar tells what kind of object anything is." (WITTGENSTEIN, 1953, § 373). This means that any kind of an object has all its meaning already defined in the language-game to which it belongs. Nothing more is required to the adequate ontological description of that entity (object) than the comprehension of its language-game. For us, ontological models go in the same direction. To know what an entity is in a physical theory depends only on the theory; and the adequate comprehension of the physico-mathematical structures of that theory is essential to accomplish such a task.

1.1.1 General view

The deflationary approach carried out here acts as a common core from where two branches of meta-ontological analysis emerge. First of all, to delimit the range of description of the possible ontologies to be associated with the physical theories, we propose a deflacionary approach that acts negatively by avoiding the dispute between realists and anti-realists. As will become clear, our intention is not to discuss the concept of truth. Our approach is just inspired by the deflationinst procedure presented in truth theory. The intention is just to illustrate how that dispute unnecessarily prejudice the formulation of ontologies. Such a move is made with the intention of protecting those ontologies from categorial errors and to shield them against the *ad hoc* influence of philosophical assumptions that are not related to the physical theories.

Under the umbrella of this deflationary approach we can find two distinct meta-ontologies. On one hand, we have an *internal* meta-ontology restricted only to the categorial analysis of the ontologies. In this thesis we deal only with that perspective. On the other hand, there is an *external* meta-ontology that is projected onto the problem related to the dichotomy realism-antirealism. As I said, we do not make major remarks on that debate, it is just described in order to evoke the importance of dividing the PTO.

The *internal meta-ontology* is a positive approach to the specific ontologies. Such an approach is extensively based on the categorial analysis of the possible ontological categories (meta-concepts) that one could use to formulate an ontology for a physical theory. This categorial analysis is a meta-ontological procedure that examine the explanatory power of the ontologies by comparing the different ontological categories (meta-concepts) in their relation with specific features of the physical theories. To some extent, the internal meta-ontology is a *formal ontology*[2] for ontologies associated with physical theories.

The *external meta-ontology* is restricted to the critical examination of the different philosophical views around the dispute between realism and anti-realism. Basically, the external examination of the PTO focus on the analysis of the relation between phenomena and physical theories. As I said before, we do not deny the relevance of the philosophical examination of the different viewpoints about realism and anti-realism, however I maintain that the creation of ontologies for physical theories must be independent of that dichotomy.

Based on those distinctions we can trace a line by using the terms “methaphysics” and “ontology” both applied to the domain of physics.

By “metaphysics” we denote those philosophical theories that are involved either in the debate realism/antirealism or in other metaphysical issues involving realist or antirealist assumptions about the physical theories. In this sense, metaphysics is a theme to be examined in the external meta-ontology. Clearly, the external meta-ontology could still be called “meta-metaphysics”.

In turn, “ontology” is conceived here as denoting the specific ontologies that can be viewed as informal models describing the physical theories. This is the main use of the term “ontology” in this thesis. Sometimes we will refer to it by “material ontology”, which has an analogous meaning to the same concept from phenomenology, that is to say, an ontology that is restricted either to only a single domain (of discourse) or one specific theory on such a domain. Consequently, ontology is a topic subordinated to the internal meta-ontology.

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[2] See Chapter 2, Section 2.1.2.1.

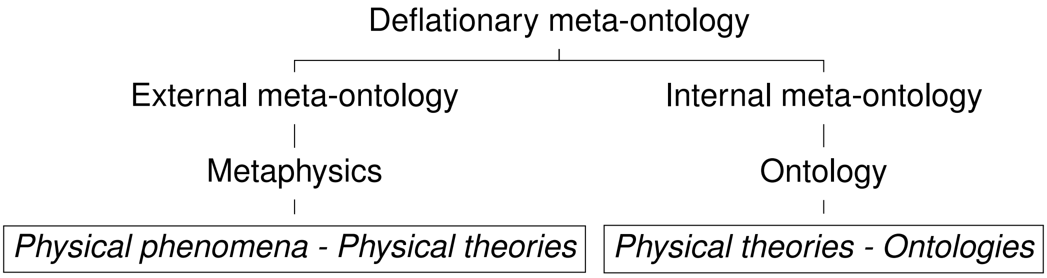

Table 2 – Analytical scheme

1.2 PHILOSOPHY OF SCIENCE, PHILOSOPHY OF PHYSICS AND ONTOLOGY OF PHYSICS.

There is an undeniable and growing specialization in philosophy. Much of such a specialization is due to a desuniversalization of the philosophical thinking. By desuniversalization I mean the abandon of the view that is possible to provide a solid, well-contained, systematic and complete philosophical examination of all aspects of reality by means of only one philosophical theory. Such abandonment has happened by many reasons. To large extent, a wide contribution for this phenomena is the increasing development of different areas of human knowledge such as empirical sciences, linguistics, sociology, and so on. Such a development has required from philosophers a high "degree of specialization" (WRAY, 2014, p. 2) on specific areas. Furthermore, there is an abandonment of the universalist view linked with specific areas of philosophy. A view introduced by universal principles such as the Kantian categorical imperative in ethics. Nowadays, such perspectives have changed enormously. For instance, ethics have branched into several directions such as applied ethics, which itself is divided in several sub areas such as bioethics, animal ethics, business ethics, machine ethics, military ethics, political ethics, public sector ethics, publication ethics, and so on. The same process happened in many other areas of philosophy.

Note that my intention is not to discuss whether such specialization is positive or not for philosophy, but just highlight its increasing role in the philosophical enquiries.

In addition, philosophy of science is not an exception, having its origins when philosophers such as Descartes have begun to compartmentalize the human knowledge in distinct areas. Descartes himself introduced, with his distinction between *res extensa* and *res cogitans*, methodological cuts that led to the Diltheyan distinction between sciences of spirit (*Geisteswissenschaften*) and natural sciences (Naturwissenchaften). Even before Dilthey, Hegel made his own (negative) contribution for the dissociation between science and philosophy. Hegel tried to subordinate science to philosophy as it was before the Enlightenment, however scientists (and philosophers) had rebelled against his speculative philosophy and the division just worsened. Since then, philosophy of science has gained great attention for its intimacy with the most reliable theories of science. All this adds up by the scientific development during the 20th century had as a result the emergence of many philosophies. Among these philosophies we could mention philosophy of biology, philosophy of chemistry, philosophy of physics, and so on.

Philosophy of physics may be defined as a philosophical examination of several aspects of physics, including the ontic status of the physical phenomena, the notion of truth and its relation with the empirical content of the physical theories, and so on. Clearly, much of these points are neglected by the physicists in their everyday practice at the lab. Those concerns are concerns for the philosopher devoted to the examination of the scientific theories. Actually, the effective study of the physical theories provides to the philosopher a way to deal with the reconceptualization imposed by the achievements of physics.

> Another pressure to "philosophize" in contemporary physics comes about because changes in our physical picture of the world require a radical revision in our conceptualization of it. When we try to accommodate the puzzling observational data that forced the new scientific revolutions upon us, we soon find that many of our prized concepts for dealing with the world rely for their viability on the presence of certain structural features of our picture of the world. In some cases these are features whose existence we don't even notice until they come under challenge from the new revolutionary physical theories. But once these features of our theoretical picture become doubtful, the concepts dependent upon them can no longer function for us as they have before and we must revise our concepts. (SKLAR, 1992, p. 9).

Furthermore, physics itself, as many other areas of human knowledge, has many deviations and specialities. For this reason, unsurprisingly, we are led to new specializations inside philosophy of physics. Right away names as "philosophy of spacetime", "philosophy of relativity", "philosophy of quantum mechanics" emerge. This increasing specialization have made difficult to defined the limits between what concerns to the philosopher and what concerns to the scientists.

In a paper called "What Is and Why Do We Need Philosophy of Physics?" Kuhlmann and Pietsch (KUHLMANN; PIETSCH, 2012) present eleven tasks or theses about what philosophy of physics is and does. Here, we present a brief list of those theses:

(i) Philosophy of physics explores three main issues: methodology, fundamental concepts, and ontology.

(ii) The boundary between physics and philosophy of physics is blurry.

(iii) Philosophy of physics is interested in foundational problems of physical theories.

(iv) Philosophers of physics often engage in inquiries that are very similar to those of physicists working during periods of scientific crisis.

(v) Philosophy of physics also encompasses text-based methodologies.

(vi) While the embedding in a mathematical framework is important, philosophy of physics explicitly goes beyond the purely mathematical content of physical theories.

(vii) Philosophy of physics takes a more pluralistic, non-partisan approach to physical concepts and theories than physics.

(viii) Philosophy of physics is historically informed.

(ix) Philosophy of physics is interested in all physical knowledge, including non-fundamental and also abandoned theories.

(x) Philosophy of physics makes normative claims about the methods of physics, and is interested in the scope and limits of physical knowledge.

(xi) Philosophy of physics has an eye on the social boundary conditions under which research in physics is carried out and tries to situate physics within the broader spectrum of human knowledge.

After all, we should be concerned because physics, as any other empirical discipline, tends to an increasing specialization; a specialization that philosophy of physics seems to be inclined to follow. In this sense, perhaps we should ask for a strengthening of the role of philosophy in the relation between the two disciplines. The assertion that "[t]he boundary between physics and philosophy of physics is blurry" (KUHLMANN; PIETSCH, 2012, p.) is worrying because major specializations in physics could lead to a weakening of the philosophy. Clearly, philosophy of physics relies on physics, however it does not mean that philosophy needs to be reduced to physics.

In turn, the deflationary approach intends to propitiate a strengthening of the role of ontology[3] in the relation between ontology and physics. The role of ontology in this relation should be independent of any specialization. To certain extent, that is why we propose a meta-ontological analysis and not an ontology applied to a specific physical theory.

Obviously, there are ontological problems related to specific theories. For instance, quantum theories have their own specificities and, consequently, their own ontological questionings. As Callender says, "[t]he metaphysics of quantum mechanics thus hangs on both a particular solution to the measurement problem and then the best interpretation of that solution." (CALLENDER, 2009). But, this specificities do not imply that we should begin to talk about ontology applied only to QM or to QFT.

Anyway, the role assigned to ontology in philosophy of physics has been well below its real relevance. Note that from the eleven thesis mentioned above just part of the first one deals with the role of ontology in physics.

> **(i) Philosophy of physics explores three main issues: methodology, fundamental concepts, and ontology.** Philosophers of physics ask methodolog-

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[3] In this section "ontology" is mostly assumed as a discipline and not as an specific ontology for a physical theory.

> ical questions about how knowledge is acquired in physics. For example, they may ask to what extent the axioms of a physical theory are supported by empirical findings. Secondly, they have a conceptual interest in elaborating and clarifying the meaning of central concepts in physics, such as space, time or probability. The third main task for philosophers of physics is the formulation and evaluation of suitable ontologies for specific physical theories. Since—in contrast to general philosophy—these ontologies are always tailored towards a given physical theory, they are often called interpretations. If 'interpretation' is understood in this specific way, it can be characterized more exactly as a mapping of certain elements of the given theory to entities (e.g. particles, properties, structures) in the world, to which the theory is supposed to refer. (KUHLMANN; PIETSCH, 2012, p. 210)

Notice that ontology receives few attention inside philosophy of physics as defined by them. I agree with them that the specific ontologies for a physical theory must be tailored (custom-made) according to the specificities of the theories. However, I disagree with them that ontology must be conceived as an "interpretation" preserving realist shades in its definition. As will be describe below, ontology and interpretation are not the same thing, and, additionally, ontology does not need to be related to any shade of realism. Actually, the apparent necessity that ontology must be committed with the dispute between realism-anti-realism is a negative effect of the identification between an interpretation of a physical theory with its possible ontologies. We will return to this point below.

Generally, ontology is viewed as a conceptual description of reality in the sense of an inventory of the entities considered to exist. In turn, *ontology of physics* can be viewed as an inventory of reality by means of physical theories. Consequently, ontology of physics deals with topics such as the reality or non-reality of physical phenomena examined by the different physical theories, the constitution of the ontologies associated with those theories, the comparative examination of such ontologies, and so on. In some sense we could call ontology of physics "metaphysics of physics". Clearly, ontology of physics is a discipline and must not be confused with any stage of the deflationary approach suggested here.

In sum, ontology of physics is conceived here as the philosophical examination of all issues related to topics like the reality or non-reality of physical phenomena until the development of specific ontologies (ontological models) for the theories. As a result, the entire PTO schema falls under the scope of ontology of physics after all.

1.2.1 An Ockhamian approach to ontology of physics

To define separately what concerns to physics and philosophy is a complicated task. This claim is based on the fact that both disciplines seem to be inclined to ask about the foundations of reality, and since physics has revelled much of those presupposed foundations, it seems very natural to merge philosophy into physics, making their common boundaries become blurry. Someone interested in differentiate one from the other in a "[...] hard-and-fast way[...]" (SKLAR, 1992, p. 3) could be impelled to replicate the same high specialization of physics in philosophy, however embedding philosophy into physics just makes the situation more opaque. It happens because the high specialization of philosophy may results in a unnecessary multiplication of the sub-areas of philosophy of physics. My claim is that ontology of physics must not follow the same specialization presented by physics. To follow it would be not just unnecessary but, also, harmful for the ontological examination of the physical theories.

Before go into the core of dispute, first it is necessary to restate the distinction between ontology as a discipline and ontology as an ontological model for a specific theory. The first is a discipline encompassing all ontological questions around the PTO, while the other refers to the exact (material) ontologies used to describe specific physical theories from an ontological point of view.

First of all, lets see what are the outcomes of a high specialization of ontology of physics. Whether we try to replicate the same specialization of physics in ontology of physics, it would be natural to expect for something like an ontology of quantum mechanics, or an ontology of spacetime, or an ontology of probability, and so on. Certainly, we could restraint ontology of physics to ontology of some specific theory or set of theories. However, such specializations are really necessary?

The situation is critical. For instance, let us assume that is possible to divide the ontology of physics into ontology of classical physics and ontology of quantum theories. After that we quickly would end up with a differentiation between ontology of Quantum Mechanics and Ontology of Quantum Field Theory. Consequently, by following the same procedure as used before we could split the ontology again and speak about some sort of "ontology of flat-quantum field theory" opposed to an "ontology of curved-quantum field theory". From there we could begin to ask for an "ontology of topological quantum field theory", which seeks for the topological invariants of both flat and curve QFT. But, perhaps, one is not interested in such an ontology and wants something more pragmatic as ontology of functional Quantum Field Theory. Anyway, this chain could be maintained *ad infinitum*. Actually, this procedure is similar to the old process of infinitization used by medieval philosophers such as Francisco Suarez. The issue with infinitization is that such practice leads to an unnecessary multiplication of the entities, and, apparently, the same goes with ontology of physics. Thus, it seems relevant to avoid such an unparsimonious approach towards ontology of physics and make use of the Ockham's razor to see that ontology of physics does not need to be ramified whenever a new physical theory arises.

In my view, ontology of physics may deal with any metaphysical or ontological concerns related to the PTO and do not need to be reduced to any class of physical theories.

Specifically, the ontological analysis carry out in ontology of physics is justified only by its own contents and methods, and does not need to be guided by any specialization at the level of the physical theories. Clearly, there are ontological particularities that belong to specific physical theories, however ontology of physics does not relies on the specific theories.

The deflationary approach propitiates the independence of ontology of physics as a discipline from possible specializations in physics. There is a clear difference between an ontological model for a specific physical theory and the meta-ontological approach used to compare different ontological models. While the first one is embedded in the physical theory and cannot be dissociated from a particular theory, the latter is just a method of analysis free from any specific physical theory. Consequently, to decide which ontology fits in the description of a physical theory will continue to be a philosophical issue extended to all physical theories and not just to some class of them. In conclusion, it is possible to say that the excessive specialization of the themes in philosophy of physics is due to the excessive weight given to the physical theories in the PTO. After all, the fact that the ontological examination orbits the physical theories does not imply in its collapse into them. Notice that there is a slight difference between the specialization of the ontological models due to the increasing specialization of the physical theories and the specialization of the discipline ontology of physics based in the same reasons. Any attempt to defend a specialization of the discipline ontology of physics based on the increasing specialization of the physical theories is just the result of a confusion between meta-ontological analysis and ontological models. The approach suggested here is goes beyond the such an specialization and can be applied to any physical theory. Ontology of physics as a discipline is the same for all physical theories, whereas ontology as a model for a physical theory is always restricted to that theory.

1.3 METAPHYSICS AND ONTOLOGY

There is a long-standing dispute about the concepts of ontology and metaphysics[4]. This two concepts have received several definitions (and names) throughout history. Different authors at different times have attributed distinct tasks to both them. For a long time they were considered the spearhead of any genuine philosophical enquiry (Aristotle), in other moments they became considered secondary in the philosophical enquiries (Kant), or just unnecessary origins of pseudo-problems (Wittgenstein).

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[4] I do not intend to do here a rescue of the well referred history of those concepts, but it is widely know that the concept of "ontology" is posterior to that of metaphysics. Even before the term "ontology" has been coined, metaphysics was generally divided into two approaches. For instance, Francisco Suarez defended a division between *Metaphysica generalis* and *Metaphysica specialis*, which was very similar to the actual division between metaphysics and ontology.

> Different authors assign different meanings to ontology and metaphysics. Some use ontology and metaphysics interchangeably (most analytic philosophers, Heidegger), others claim that ontology is broader than metaphysics (Meinong, Ingarden), still others that metaphysics is broader than ontology (most traditional philosophers, Hartmann). (POLI; SEIBT, 2010, p. 1)

In general, all definitions for metaphysics and ontology carry with them the pretension of universal explanation about the nature of the entities at hand. Some definitions are very wide in their purposes.

The problem with this kind of perspective is the continuous attempt to grasp many (generally all of them) aspects of the "reality", and it becomes a real problem when one is trying to focus only on one part of that reality; which is exactly the case in ontology of physics. As said, in ontology of physics we should look deep into the physical theories to avoid mistakes that emerges when one is trying to push conceptual assumptions that cannot be derived from the theories themselves. To avoid this practice one should opt for a focal procedure that takes into consideration just the physical theories and nothing more.

Thus, engage in the dispute about how one could define ontology and/or metaphysics is not our intention here. Actually, I just ignore the terminological dispute and make a clear cut between those philosophical disciplines by assigning different tasks for each one of.

First, we have metaphysics that is more general and, in some sense, more fundamental than ontology. By metaphysics applied to physics I conceive, in a very standard view, any philosophical approach that examines the question about the reality or non reality of the possible entities that could be underlying the physical phenomena, or any other position that just considers the examination of those phenomena in the light of some kind of realism or anti-realism. Additionally, there are questions about truth-making, grounding, and so on. All this questioning is considered here as an issue that only metaphysics should deal with. After all, this questioning does not have any primacy over the definition of the ontological models and neither need to be take into consideration in formulating these same models.

Second, we consider ontology as dealing only with the relation between the physical theories and its possible ontologies, nothing more is considered. Thus, an ontology would be some kind of a model for a physical theory. That is to say, by examining the physical theory the ontologist must be able to generate liable ontological categories to model the main concepts of a physical theory. In this sense, the concepts proposed in the ontology actually are meta-concepts over the concepts in the physical theories.

Inserted by Granger (GRANGER, 1994), the idea of philosophy (ontology in our case) as a meta-conceptual analysis is very useful at any domain of investigation.

> Em ce qui concerne plus précisément ler apport du concept methématique naturel à celles des constructions mathématiques qui em conservent le nom, "nombre" et "espaces", les mieux est encore, croyons-nous, de recourir à la métaphore wittgensteinienne de "ressemblance de famille". Les concepts de "nombres réel", de "nombres algébrique", de "nombres complexe", ou d'"entier de Gauss" ne sauraient être considérés comme les espèces d'um genre "nombres", qui serait défini au moyen de traits axiomatisés. On reconnaîtra cependant que ce sont des nombre, si l'on prend ce term désignant non pas la forme réduite à une structure fixe du concept mathématique d'entier naturel, mais um concept philosphique – um méta-concept – delimite par des caractères exprimés dans um méta-langage, dont la réalisation typique, et "achevée" au sens exposé plus haut, est justement le nombre naturel. (GRANGER, 1994, p. 165)

In the case of ontology, ontological categories are meta-concepts for the domains to be examined. By that, ontology acquires the status of categorial analysis (meta-conceptual analysis) able to analyze a physical theory and extract from there the general aspects that should be described by means of adequate ontological categories (meta-concepts). In turn, an ontology in this sense is a theory that provides meta-concepts to model concepts of the physical theories.

Depending on the domain and the aims of the investigation, the ontologist can obtain high degrees of meta-conceptual description. For example, in QFT the theoretical concept of a photon may be described by means of meta-concepts involving not only the entity photon but also as token of the type *boson*. Additionally, we could consider features involving potentialities of the photon as an interacting field, or aspects related to measurements processes, or even intrinsic behaviours as locality could be examined by means of meta-concepts. Again we could return to the citation above and make the same move as made by Granger. In any case, a quantum field relies on the mathematical structure of a field, and "field" is just a name like "number" referring to distinct mathematical objects. In this case, "field" may denote scalar fields, vector fields, etc.. In addition, since quantum entities in QFT are defined in terms of those structures, it would be natural for the ontologist take into account those structures to develop the meta-concepts to be used in the ontologies. Clearly, as one may argue, a field is not a quantum entity, from that we could insert other meta-concepts differentiating them. For instance, in the case of a photon we could take it as a natural kind[5] such as a cell or a chair, while the field could be viewed as an abstract kind. On other hand, it is really complicate to define what is a natural kind is QFT. Take again the case of a photon. In QFT a photon is a particle in some sense, however in approximate methods (perturbative QFT) it is often interpreted as a virtual particle. For example, when an electron and a positron destroy each other a virtual photon is "liberated", and from this a pair quark-antiquark is created. Well, a virtual photon is not an entity but just a perturbation

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[5] Clearly, the entities of the quantum domain entail in revisions for the own notion of natural kind, however I do not intend to take that discussion here. For a discussion on the matter see (DALLA CHIARA; DI FRANCIA, 1993, p. 269).

introduced in the formalism to make sense of calculations. This way, "photons" can be abstract as fields as well. If we want to maintain the concept of natural kind in this situations, then we need to change the concept itself, or at least do not use it.

So then, to represent or explain the (theoretical) concepts of a theory different philosophers might suggest distinct ontological approaches involving different meta-concepts.

In spite of the high degree of description that one could achieve by inserting more levels in the ontological description of a physical theory, I prefer just to put one level; the level of the ontological categories as meta-concepts. As I see it, the additional structures and ramifications of the theoretical concepts can be considered in the same level as long as we do not put all of them in a vertical hierarchy. If we assume that is possible to take just some of the levels and set aside the rest, then we are denying the straightforward interdependence between structures and concepts.

For example, the momenta of a photon moving at speed of light in vacuum as well as its mass are always the same; and if one intends to describe these properties, then this one must consider the relativistic spatiotemporal structure underlying the theory. Note that, even though the property is the "end" of the description, the additional structure is essential to that property be what it is. Accordingly, in order to define what the property mass means one should define why mass is conserved under some symmetry, that is, a translational symmetry. Clearly, mass is not the same as a translation, however without the existence of that symmetry is impossible to defined this property. Actually, it does not make any sense to speak about mass without taking into consideration the structural *conditions* for its existence. After all, it seems an error to imagine that properties such as mass should be consider at the end of a hierarchic chain of structures (as a result). Different from mathematics, where there is a cumulative (vertical) chain of structures, in physics all structures work, we could say, "at the same time"[6].

Finally, I would like to advocate for the adequate differentiation between the concepts of the theory and the meta-concepts of the ontology. Although the ontologists in physics being aware of the structural assumptions involving the theories, they in general commit some sort of methodological (meta-ontological) mistakes.

(i) Or they ignore the structural assumptions and just presume the possible categories to be used;

(ii) or, despite been aware of the difference between the concepts of the theory and the meta-concepts of the ontology, they still are unable to make a reasonable connection between them;

(iii) or they chose just one specific situation in the theory and try to describe it by

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[6] See Table 11.

means of a specific category, but when they try to use the same category in major contexts in the theory they discover the limitations of their approaches;

(iv) or even being attentive with the concepts of theories, they lose the track and collapse the ontological categories (meta-concepts) in the concepts of the theory.

All this situations are possible; all of them are examined in this thesis.

1.4 DEFLATIONARY APPROACH

In truth theory the concept of truth can be formulated in many ways and, depending on the philosophical standpoint, the ontological status of the concept can be conceived in many senses (HAACK, 1978, p. 86). This way, an important issue for many philosophers is the reality or non-reality attached to the concept. In truth theory the concept of truth can be allocated in different approaches, each one having its own understanding about the nature of the concept. Large part of those theories are related with realist or anti-realists assumptions. According to truth theory there are four major lines of conception of the concept of truth: correspondentism, coherentism, pragmatism, and deflationism[7]. Here I roughly present the general lines of the main theories, even though each one of them has several ramifications.

The correspondentist view defends that language mirrors reality, and the concept of truth relies on the possible truth-makers fulfilling such a reality. Wittgenstein in his *Tractatus* presents one of the most iconic and influential correspondentist conceptions[8].

In contrast to the correspondentist, the coherentist perspective tries to avoid the question about truth-making by asserting that a statement is true only if it is part of a maximal consistent set of sentences. Among the coherentists the role played by Quine must be emphasized, he holds the view that truth is obtained just inside the "[...] full body of our beliefs [...]" (W. V. QUINE, 1978, p. . 16), in which a sentence is true only if there is a mutual inferential system of beliefs that justify that sentence.

In turn, the pragmatist view holds that a true sentence is any sentence that is adequate to the assertions of a specific domain, generally the scientific one. One example of a pragmatist theory is the quasi-truth theory, which is syntactically equivalent to the coherentist view. Briefly, in quasi-truth, a sentence is true only relatively to a specific set of sentences. Often, the sentence may belong to a bigger set containing the negation of that sentence, leading to a contradiction and making the system inconsistent as a whole. In order to avoid such outcome, in quasi-truth theory we just consider the truth relatively to the consistent sets, which are preferentially referred to "[...] some knowledge base [...]" (DA COSTA; FRENCH, 2003, p. 148) like a scientific theory.

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[7] Here we does not consider the semantic concept of truth due to the fact that is may be viewed as coorespondentist (Tarski's view) or deflationist. See (HAACK, 1978, Chapter 7), (KIRKHAM, 1992, Chapter 5).

[8] See §§ 4, 4.01, 2.21, 2.12 (WITTGENSTEIN, 2013).

Last but not least, the deflationist claims that the concept of truth is dispensable for any statement. For the deflationist the predicate "true" does not attribute nothing new to the state of affairs in a statement, thus becoming *redundant*. For the deflationist, a statement like "Jupiter is bigger than the Earth is true" has no further meaning than the statement "Jupiter is bigger than the Earth". The predicate does not add anything to the fact that Jupiter is bigger than the Earth. Even though it is a polemic issue, philosophers such as Kant, Frege and Ramsey have defended such a view.

In the end, the dispute among those views is in close relation with the debate between realists and anti-realists. Loosely, the correspondentist holds a realist position about the truth predicate whereas the coherentist and the pragmatist sustain an anti-realist approach towards truth. In turn, the deflationist does not attribute any ontological charge to the truth predicate. Consequently, his claim is that there is no need to enter the dispute between realists and anti-realists.

My aim is to appeal to the same leitmotiv of the deflationism, that is, to avoid the dispute between realists and anti-realists. However, my claim does not involve major considerations about the concept of truth but about the avoidable debate between realism and anti-realism around the most adequate ontologies for a physical theory. When one is trying to make an examination of the possible ontological models for a physical theory, this one is generally committed with some shade of realism or anti-realism. My claim is that the examination of the ontological models for a physical theory must be independent from such dispute.

There is a widespread practice among philosophers of science when they are considering the specific ontologies for physical theories, that is to say, they do not distinguish the study of the ontologies from a presupposed reality to which the ontologies are linked with[9]. In fact, this kind of assumption is due to a confusion about the limits between the domains of discourse of both ontology and physics. If I ask for the domain of reference of a physical theory, the immediate answer will be an specific set of physical phenomena, and that is correct. Physics is about the description and prediction of the behaviour of some set of phenomena. However, when one asks about the domain of reference of an ontology (ontological model) the situation becomes blurry. What is the domain of reference of an ontology, the physical theory or the physical phenomena? As I have anticipated, ontologies must be projected only onto the physical theories.

For instance, if we were to ask about which are the possible truth-makers of the empirical statements of a physical theory, then we would be allowed to make room for the metaphysical debate realism/anti-realism. The concerns about the reality or non-reality of the phenomena or the effectiveness of the physical theories on that description are genuine problems. However, a genuine assumption like that can rapidly become the source of many complications for the ontological inquiry in physics. Note that, although

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[9] See (SKLAR, 1992).

justified, the concerns about truth-making is not so far from the concerns about the meta-conceptual descriptions of the conceptual framework used by a physical theory to describe a set of physical phenomena. Generally, ontologists are not attentive to the difference between the description of the conceptual framework and the description of the phenomena.

By neglecting the aforementioned distinction one could easily assume the wrong supposition that ontological models would have two domains of description: the conceptual framework and the phenomena. In this avoidable case the physical theories would be viewed as a *medium* for the ontological examination and not as an end.

Additionally, by assuming two domains of reference, there would be conflicting interests. Both the physicist and the philosophers, although with different domains of discourse, would be trying to speak about the same domain of reference, the phenomena. In this case, the philosopher would be trying to say more than the physicist by committing a transgression of the descriptive limits of the ontological model. In other words, by directing the ontological description towards the phenomena and not only to the theory, the philosopher would commit a clear categorial error. Accordingly, my claim is that the only domain of reference of the ontologies must be the physical theories themselves and not the physical phenomena. Thus, we should say that the ontologies do not require any truth-maker or even make any reference to the physical phenomena; this role is exclusive of the physical theories.

After all, this position has two great advantages. First, it is much more simple than the usual (transitive) position, since it avoids the dispute realism/anti-realism. Second, it prevents the ontological models from being contaminated with *ad hoc* assumptions that are not present in the physical theories, but that are, in general, present in the dispute between realists and anti-realists.

This last point is based on the fact that philosophers and even physicists have tried to push their metaphysical/ontological presuppositions into the physical theories or in the “ontologies” associated with them. This leads to unnecessary discussions about concepts that cannot even be extracted from the conceptual framework of the theories *per se*. For instance, we just need to remember of how Aristotle and his crystallized conception of the universe had dominated the philosophical and scientific thinking for centuries[10]. Obviously, physicists make all kinds of realist presuppositions about their theories, but the steps that lead a physicist from everyday assumptions to a well-placed theory are not a theme of ontology of physics. As I conceive here, the deflationary approach considers physical theories as *given*. From that, ontological models are never

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[10] Clearly that there are prime examples of philosophers that were able to achieve great results by appealing to physics and mathematics to base their own philosophical views. The examples are various. Kant and his theory of pure forms based on a Newtonian-Euclidean perspective. The Leibnizian metaphysics based on the infinitesimal calculus. Descartes, who grounded his *res extensa* on intuitions emerging from his own formulation of analytic geometry. Among others.

about the physical phenomena but just about the theories.

1.4.1 Physical objects and classical ones

In this section I provide an example of how ontologies can be set up without making reference to phenomena.

“What is the relationship between everyday objects and the entities posited by physics?” (FRENCH, 2010, p.) This is a question that is impossible to ignore when ontology and physics came up together. Philosophers of science have paid enormous attention to the problem.

First of all, one critical point is that everyday objects, here understood only as entities disposed in space and time, are also the theme of domains of discourse, that is to say, they are *used* in specific language-games as tools. For example, if I were working at a rail station and I give to a passenger the information that the train exiting station A would reach the station B one hour later because of a problem in the railways tracks, then the information would be perfectly understood. However, if I changed the word “train” by “unicorn” and the word “railroad” by “rainbow”, then the information would not work as intended. For a philosopher the origin of this strangeness could be caused by a lack of conformity with the language-game at stake, or with the fail of the information to fulfil our common sense. Anyway, a clear dispute may be open on this.

On other hand, despite the several examples involving trains going from one station to another station, in CM there is no interesting by the physicist for trains, railroads or railways stations. As long as the values of the properties (mass, energy, and so on) are maintained, we may easily replace trains by unicorns and railroads by rainbows, and nothing would change for the physicist. There is no reference to entities with any kind of a extension in CM, just points in a coordinate system. For instance, the trajectory of any entity in CM can be viewed as just a geometric line in a coordinate system.

I will address some attention to both the notion of everyday objects and that of classical entities as considered in CM. Thus, a change in the question above is needed. Properly, we should ask now: *What is the difference between everyday objects and classical objects of CM*[11] *?*

First, I would like to address some attention to everyday objects and see how they can be conceived. Wittgenstein (the first) has one unique way to define concrete objects, he says that “[s]pace, time and color (be colored) are forms of objects” (WITTGENSTEIN, 2013, p. 2.0251). That is to say, everyday objects are objects of perception well known by its properties and by their locations in space and time. Additionally, he says “Objects contain the possibilities of all situations” (WITTGENSTEIN,

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[11] Since I am considering just CM, *fluid* entities such as liquids and gases are not considered in this example. Those cases are not examined in CM. However, they can still be made subject of analysis of any ontology that take into account the representation of physical concepts that involve spatial extension. See (KOTARBINSKI, 1968, p. 44).

2013, p. 2.014). Thus, according to him, everyday objects have all their possibilities in different state-of-affairs.

In a similar way, van Inwagen has given its own definition for material objects.

> Like most interesting concepts, the concept of a material object is one without precise boundaries. A thing is a material object if it occupies space and endures through time and can move about in space (literally move about, unlike a shadow or a wave or a reflection) and has a surface and has a mass and is made of certain stuff or stuffs. Or, at any rate, to the extent that one was reluctant to say of something that it had various of these features, to that extent one would be reluctant to describe it as material object. (INWAGEN, 1995, p. 17)

It is interesting how he makes a specific characterization for material beings, here understood as everyday objects. He explicit say that material objects "move about", which it seems to mean that we should not confuse material emtities with what we could call a "virtual" notion of them. The idea of differentiate physical/material/everyday objects from other kinds of entities by attributing to them a material reality is what makes classical objects so particular.

Consequently, we could say that classical objects from CM are neither colored nor have any extension. But they do not have such properties because they are that way by nature, actually, they do not have those properties because such properties are not defined for them. On other hand, classical objects also contains all theirs possibilities (group structures and degrees of freedom[12]) which are defined in the theory. How such possibilities are possible and how they are used to define the entities?

First, in CM we chose a system of reference. Since space and time are intended to be absolutes in CM, we may choose the Euclidean space as the preferable one. After that we fix time as a parameter in the coordinate system, while the remained dimensions of the space are used to define specific points representing the physical system. By adding time we become able to apply the entire set of the Galilean transformations, the symmetry group of CM. According to Noether's Theorem, since we have a group of symmetries, we can define the conservative laws of the theory. By fixing the conservative laws we obtain the equations of the theory, which are in CM the motions equations. These equations are invariant under transformations, which means that depending on the transformation some physical property is preserved. The aforementioned possibilities are conditioned by those structures, more specifically, by algebras that rule the transformations. Additionally, since those transformations are the Galilean transformations, we could say that a classical entity or a point-like particle is a "Galilean particle" (CASTELLANI, 1998, p. 191).

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[12] Clearly, the ontologist could consider different formulations for CM. For example, it could be interesting to exam if the Hamiltonian and the Lagrangian formulations could provide different ontological categories for the philosopher. After all, although being equivalent formulations for CM, they are structurally different. As pointed out by North (NORTH, 2009), the symplectic structure for the Hamiltonian formulation incorporates less structure than the Lagrangian. See also (FRENCH, 2014, p. 28)

From that we can see how is possible to identify the features necessary to describe classical objects, including their possibilities, without appealing to other domains than the physical theory. In this sense, once more we can advocate for ontologies based only on the theories.

1.4.2 Realism, anti-realism and realism again

The realist usually claims that somehow the ontology should say “something else” or “reveal” something behind what the physicist says about the world (*Weltsanschaung*). Unlike that position, I believe that is a mistake to assume that the ontological approaches to physical theories should say more than the theories themselves. Go beyond the limits of physics and postulate blurry concepts that are not related with the theories is a misconception about the role of ontology in this regard. This misconception generally has its origins in not so clear assumptions from metaphysics. Frequently, these assumptions are tacit assumptions for the anti-realist as well.

From the above, the naive realism states that our descriptions of the physical phenomena are always somehow linked with some kind of a hidden reality (Plato). On other hand, the naive (radical) anti-realism states that there is no reality at all but just the representation of a subject (Berkeley). The radical ceticist says that is not possible to affirm that there is some reality (Pirro), while the mitigated ceticist says that is possible to live with such enigmas but not to solve them (Hume).

For many of them reality may exist by itself but it cannot be known; others defend that reality must be identified with the immediate phenomena (Husserl); others still believe that science is a bridge towards the understanding and unveiling of such reality (D. Armstrong); and so on.

After all, the debate among realists leads to all kinds of conflicts, including the debate about what may be considered real and what could not be. For instance, some realists defend that physical phenomena are real, but things like numbers and/or literary characters are not. In this sense, the concept of reality itself is continuously changed. Such hybrids (realists/anti-realists/realists) positions are very common. Among them there are those that defend levels of reality, which can be conceived in degrees of what is more real, including all genres of hierarchies. In this last case, to define what is a criteria for such hierarchization is a difficult task. Some philosophers just appeal to the immediate experience to say that some entities related to perception are more real than those that are not (Quine). There are also agentive realists perspectives that are more dynamical since they defend that reality is a reality of actions.

Although is possible to define what realists and anti-realists uphold, the line that divides both positions is still very fuzzy. Let me give an example of such situation.

In his book *Scientific Image* van Fraassen, who calls himself as an anti-realist, presents his definition for the task of science as the “construction of models that must be adequate to the phenomena, and not discovery of truth concerning the unobservable" (VAN FRAASSEN, 1980, p. 22). Basically, what he is saying is that does not matter what is behind the phenomena, what is relevant is whether the theory adequately (pragmaticaly) describes those phenomena. This view defended by him is what he called "constructive empiricism". According to him, this conception of the task of science leads towards an anti-realism. However, the situation is more complicated, and, as I will illustrate, van Frassenn's position could also be considered a realist one. After all, since there are levels of realism, perhaps we could find one in which constructive empiricism fits in. Here I suggest two candidates: a Kantian realism and a Husserlian realism.

The first is based on the hypothesis that the phenomena hide some possible truth about something (unobservable/things-in-themselves) that sustains those phenomena. It seems that van Frassen is arguing against this kind of realism, or at least pragmatically avoiding it.

The second is more subtle and defends that the question about things-in-themselves is irrelevant because reality is build up on only phenomena. The immediate phenomena is what is considered in this realist perspective.

Now we can take a realist position about phenomena like that presented by the Husserlian phenomenology. Generally speaking, in this case philosophy is always about phenomena because all we can have are phenomena. Following this view, we can reinterpret the statement "construction of models that must be adequate to the phenomena" by saying that we still can fit this view on some sort of realism. In this moment, as usually done in phenomenology, we could say that there is no sense in talking about unobservables but just about phenomena. Remember that phenomenology is one kind of realism. Consequently, there would not be any sense in questioning about what there is beyond the phenomena, since all we can get are the phenomena. Clearly, the way those phenomena are interpreted by science determine what they mean. This situation is critical since we could find examples that could apparently contradict our attempt to convert van Frassen to realism. For instance, take the following case from astrophysics[13]. In this situation, two quasars, $Q1$ and $Q2$, are discovery side by side. However, by means of General Relativity, the scientists discover that there is only one quasar whose light has been reflected by effects of gravitational lens along some other heavy mass body; the galaxy YGKOW G1, "A" for short. Well, it seems that we have two different phenomena, $Q1$ and $Q2$, connected with the same entity Q[14]. In this sense, van Frassen could argue that both phenomena are not real, or even to affirm that the possible "real" phenomena, Q, is hidden behind A. Actually, what happens according to our Husserlian view is that $Q1$ and $Q2$ are really observed according to what they are (phenomena), and in spite of neither of them being related to an specific entity each like

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[13] See (FRENCH; KRAUSE, 2006, p. 211).

[14] For an analysis on the referencialist issue implied for this situation see (DALLA CHIARA; DI FRANCIA, 1993, p. 254-268).

Q' and Q'', they are still phenomena for Q. And more, $Q1$ and $Q2$ are also phenomena for A in relation with B. The gravitational lens effect is only an effective description of the universe because phenomena like these occur. In this sense, we could assume a realism perspective about phenomena. As a result, we could paint van Frassen's position with some shades of realism.

Notice, that I am not saying that van Frassen is a realist after all. In fact, he is not. What I Am doing is just just illustrating how is possible to cross the line between realism and anti-realism without major problems. That is why I am arguing that the dispute realism/anti-realism do more harm than good for the working ontologist in physics.

Additionally, we should say something more about the scientific realism. Clearly, scientific realism resides in the dichotomy between "[. . .] structure and nature [. . .]" (PSILLOS, 1995, p. 44) whereas anti-realism lives in the hope that its *pessimistic meta-inductions* become reality. The realist, arguing that there is *no miracles* in the scientific success, seeks to sustain its position by means of several sorts of realism in science. After all, they are too many.

Again, we are not arguing that the dispute is pointless. In fact, it has its own meaning, however for the ontologist this metaphysical dispute should not represent a matter to be considered when one is making up ontologies. To be honest, the deflationary method has several points of contact with the structural realism[15], however, above all, we put the question of reality or non-reality of the structures aside.

1.4.3 External meta-ontology: from phenomena to theory

When we deal with the problem of comparing different metaphysics we move from the level of postulating and characterizing concepts inside a specific metaphysics to a meta-ontological (meta-metaphysical) level of analysis of those metaphysics. Notice that this meta-ontological level is not the deflationary one; it is under the umbrella of the deflationary approach. To differentiate this level from the meta-ontological level directed towards the ontologies themselves we call it "external meta-ontology" in opposite to an "internal meta-ontology". In the end, both them are sublevels of the deflationary (meta-)meta-ontology.

One example of the external approach could be the analysis perpetrated in truth theory, where we can talk about the concept of truth in science from different perspectives. For instance, when one philosopher goes for a coherentist defence of the concept of truth and another one goes for the correspondentist point of view, the comparative analysis of both approaches is made outside of each particular theory in a meta-ontology, which is, with our differentiation, the external-meta-ontology. The exam made in the Section 1.4.2 is a clear example of an external analysis.

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[15] See (FRENCH, 2010, p. 91).

To take another example. The dispute between ontic structural realism and epistemological realism in philosophy of science. It is a clear case of an external dispute, since the debate goes around the reality of the physical phenomena and/or the reality of the mathematical structures[16]. Such dispute is examined in the meta-ontological level that is concerned with the metaphysical questions around the relation between physical theories and physical phenomena.

Although that is a topic of great relevance, here I just addressed attention to the relation between ontologies and physical theories. From that, the present investigations are concerned only with the internal meta-ontological analysis of the relation between theories and ontological models.

1.4.4 Internal Meta-ontology: from theory to ontology

The internal meta-ontology is the analysis directed towards the comparative study of the different ontological models that could be associated with one only physical theory. As we have stated before, ontology[17] is understood here as a material ontology, that is to say, when one is describing the general aspects of a physical theory by means of ontological categories (meta-concepts), this one is trying to create a “model” to that theory. After all, many ontologies can be associated with the same physical theory. This situation is described by the Metaphysical Underdetermination (MU), which will be examined later[18] from the deflationist perspective. One of the tasks of the internal meta-ontology is to analyze those ontologies by taking the ontological categories that could fit in a description for a conceptual framework. After all, our view is different from others because we divide the meta-ontology in two different domains of application to escape from the unnecessary debate between realists and anti-realists.

Usually, there is no clear line that could divide the pure exam of a theory in the light of the ontologies, from the tacit presuppositions that are implicitly inserted in the ontologies by philosophers or by physicists. The deflationary approach seeks to delineate that line by avoiding any presupposition that are not related to the physical theories. Any misleading assumptions originated from the everyday practice or any conceptual heritage that is strange to the relation *physical theory-ontology* is avoidable in this approach.

Finally, I would like to stress that the internal examination defended here must not be understood as an anti-realist position about phenomena, or even as a structural realist view about the structures that hold the physical theory together. Above all,

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[16] Actually, the ontic structuralist does not advocate for the reality of the mathematical structures, but for some kind of persistence of the underlying structural features that are present at different scientific theories. See (FRENCH, 2014, p. 137-138). (FRENCH, 2011, p. 218).

[17] This sense of ontology is different from the meaning of ontology as a discipline. See Section 1.2 in the current chapter.

[18] See Section 1.5.1.

the present investigations are not "[. . .] inimical to realism [. . .]" (CHAKRAVARTTY; SUGDEN, 2011, p. 178) neither to anti-realism.

1.5 BREAKING THE TRIAD: PHENOMENA-THEORY-ONTOLOGIES

To acquire the status of a (meta)meta-ontological method the deflationary approach has several obstacles to surpass (or ignore). Since we fight against the idea of living under the shadow of the realist/anti-realist dispute around the physical phenomena, it is now time to pay attention to the theses which nourish that dispute. Properly, when we direct our attention to physics we cannot forget well known thesis such as the metaphysical underdetermination (FRENCH, 2011, p. 21-22) or the ontological commitment (QUINE, W. V., 1963, p. 8). In the next two sections I intend to demonstrate how the PTO can be separated into two different areas of analysis without abandoning both the metaphysical underdetermination and ontological commitment.

1.5.1 Metaphysical Underdetermination

To some extent, our investigations cannot escape from the shadow projected by the thesis of metaphysical underdetermination. As we know, there are several variations of metaphysical underdetermination[19]. Although here is not the place to go extensively on those matters, it is still possible to resume those variations in two main kinds of underdetermination:

- (i) underdetermination of the physical theories by the physical phenomena and (FRENCH, 2014, p. 21);
- (ii) underdetermination of the ontologies by the physical theories (FRENCH, 2014, p. 21).

Notice that the relation (i) between phenomena and physical theories is apparently clear. There are several criteria establishing when a physical theory is linked to a set of phenomena and when it is not. And even with different physical theories it is still possible to find some sort of equivalence among them[20], which is the case of the Hamiltonian and Lagrangian formulations for Classical Mechanics. On the other hand, metaphysical underdetermination (ii) states that a physical theory can determine more than one ontology, however, in this case, there is no criterion to determine which ontologies can be associated with the physical theories.

Properly, both kinds of underdetermination rely on the assumption that the road that goes from phenomena until ontology is a one-way street, mainly, because the

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[19] See (FRENCH, 2011).

[20] See Appendix B, Section B.0.1.

metaphysical underdetermination does not permit to reconstruct retrospectively the path that goes from the theory to ontology. Since only the theory deals with the phenomena, it seems clear that any ontological inquiry about a physical theory cannot be a direct ontological inquiry about the phenomena. Additionally, it is a mistake to consider the theories as a means for the ontological description of a presupposed reality.

With that in mind, we can say that there is no transitivity between phenomena, physical theories and ontology. In addition, the metaphysical underdetermination requires that things go that way. If it was possible to make valid ontological considerations about the phenomena without appealing to the physical theories, then we would not need the metaphysical underdetermination at all. In such case, the first underdetermination would be enough.

Since our considerations intend to provide ways to look inside the physical theories and extract the structural elements that must be modeled in the ontologies, our position can be understood as belonging to the situation stated by the metaphysical underdetermination. Above all, ontological models must be maintained out of the range of the phenomena.

1.5.1.1 Hypothesis: metaphysical underdetermination cannot be defeated

By the first underdetermination several physical theories arise to give sense to a set of physical phenomena. By the metaphysical underdetermination many ontologies arise to describe the ontic features of the physical theories. The difference is that distinct physical theories may be compared and proved equivalent in several ways (empirical, formal), whereas ontological models for the theories cannot be subject to the same test. Consequently, the methodological disputes around the best ontologies for a physical theory remains a no-man's land.

Hitherto, there is no formal proof or method to compare and prove that there is an undeniable link between ontologies and physical theories. In this sense, there is no formal proof that could compare and say that there is some kind of isomorphism between ontologies[21]. But, if such method would be implemented, could it demonstrate that the metaphysical underdetermination does not hold?

Well, for now such proof is not possible yet, but it does not forbide us to imagine a negative answer to such a question. Thus, we do not need such formal method to imagine how the situation could be in that case.

First, I would like to assume four hypothesis: i) physical theories can be reduced to formal structures; ii) ontologies can be formulated as formal models (ontological models); iii) there is a formal method to demonstrate whether an ontology can be faithful associated with a physical theory or not; iv) it is possible to compare those

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[21] I say this in the present context, however it is possible to compare or translate ontologies formulated in formal languages. See (COCCHIARELLA, 2007).

ontological models in order to discover whether they are isomorphic between them or not. The situation is proposed as follows:

Be $\mathbf{O} = (O_1, O_2, ...O_j, ...O_k)$ a class of ontological models for a physical theory T. Let us assume that is proved by means of the formal method $\mathbf{M}$ that a physical theory T has only two ontological models, O_i and O_k. Now, lets assume that by means of $\mathbf{M}$ is possible to decide if O_i and O_k are isomorphic between them or not.

Only two results are possible: or O_i and O_k are isomorphic or not.

i If O_i and O_k are not isomorphic, then the metaphysical underdetermination is valid.

ii If O_i and O_k are isomorphic, $O_i \equiv O_k$, then the metaphysical underdetermination is still valid. After all, it is expected that, like what happens with isomorphic structure in category theory, the ontologies O_i and O_k would continue to be two different ontologies despite being structurally isomorphic.

At this point, if our hypothesis proceeds, it seems that metaphysical underdetermination is insurmountable, and metaphysical underdetermination continues to be an established fact for any ontological investigation on physics.

1.6 UNDERDETERMINATION AND ONTOLOGICAL COMMITMENT AFTER DEFLATIONISM

At this point, one could ask about the relation between our investigations and Quine's thesis of Ontological Commitment (OC)[22]. First of all, since these investigations go under the metaphysical underdetermination and not under the first underdetermination, our investigations have little to do with the OC. Let me explain this point.

In the first place, it should be clear that the OC is a necessary implication of the first underdetermination. Notice that a physical theory is underdetermined by a set of phenomena which it aims to describe. In order to deal with those phenomena the theory compromises itself with the existence of some entities to make sense of those phenomena. Such entities are represented in the theory as part of a conceptual framework. As a result of this procedure, the OC comes to the game in the usual way[23]. Roughly, the OC can be viewed as the inverse application of the first underdetermination. The first underdetermination goes from the phenomena to each physical theory, whereas the OC, in this case, acts as a response going from each physical theory towards the

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[22] Here I consider just the case of the entities of physical theories, other kinds of entities as imagined by Quine are not considered here.

[23] See (QUINE, W. V. O., 1969, p. 97).

phenomena, and not in the direction of the possible ontologies to be attached to the physical theories.

For this reason we might say that each scientific theory is committed with a portion of reality, although it is not committed with its possible ontological models. Notice that we describe the entire notion of the ontological commitment proposed by Quine without appealing to the metaphysical underdetermination.

Now, we can finally return to the metaphysical underdetermination. In the moment that a physical theory becomes *committed* with the existence of some entities, e.g. observable postulated by the theory, then it is possible to attach some ontology, in *stricto sensu*, to it but not before that. The situation is simple, what one calls ontological commitment is the attribution of existence to some entity, whereas the use of ontological categories to describe such entities occur only under the scope of the metaphysical underdetermination. That is why we can say that, for example, photons exist in a physical theory, but we do not say that substances exist in a ontology. The entities of a physical theory exist, the ontological categories used to describe them not[24]. These clarifications helps us to understand how different ontologies are underdetermined by the same physical theory without making this theory dependent on those ontologies. It validates the idea of a non-transitivity between phenomena, physical theories and ontologies. Properly, in the PTO the way that goes from the phenomena to the physical theories (PT) is under the scope of both the first underdetermination and of the ontological commitment, whereas the way that goes from the physical theories to the ontologies (TO) is under the scope of the metaphysical underdetermination. There is no relation that goes from the phenomena to the ontologies, or vice-versa. This makes the constitution of the ontologies independent of the phenomena.

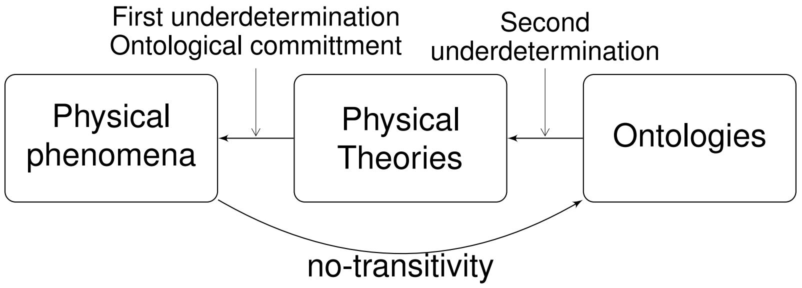

Table 3 – PTO

Thus, the entities postulated by the theory rely on the OC, whereas the ontologies associated with the theories rely on the metaphysical underdetermination. It reveals why the ontologies do not deal with the particular entities of the theory, but only with the conceptual frameworks that describe how those entities are possible in

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[24] Clearly, this is a controversial point. See (QUINE, W. V. O., 1969, p. 98).

the theories. Consequently, the ontologies should not treat the physical theories as a means to describe some portion of reality but should treat them as an end or limit of that description (non-transitivity). In this case, ontology is about ontological categories and categorial structures, whereas physical theories are about the entities postulated to explain some set of phenomena. Here is possible to differentiate the actual entities postulated to exist by the physical theories from the ontological categories postulated by the ontologies in order to describe those entities. Notice that the existence of the entities for the physical theory is an essential aspect, whereas for the ontologies this is not a case of existence of the categories. The ontological categories are just a tool in the description of what the theory is saying and nothing more.

Let us take an example. In physics, the concept of light is related with that of the photons, which are the entities with electromagnetism is committed. The entity "photon" is postulated to exist and its description in eletromagnetism is made by the physico-mathematical structure of a eletromagnetic field. Now, if we want to describe such phenomena in a ontology, then we do not deal with the phenomena of light but just with the conceptual description of such entity, which is entirely contained in the mathematical structures of the theory. Thus, we could say that there is no ontology about electrons but just physical theories dealing with electrons; and there are no physical theories about substances, tropes, and so on but just ontologies.

A final question could also be raised on this matter: Would the metaphysical underdetermination be a case of ontological pluralism as that represented by the OC?

As we described above, in the OC we are dealing with the relation that goes from phenomena to the theories associated with them, and there is plenty room for a pluralism of theories, each one of them proposing a different conceptual framework to describe such phenomena.

In the case of the first underdetermination we have an analogous situation. Different theories are associated with the same set of phenomena, being compromised with different entities. However, it is possible to see that, for instance, in the case of QM things goes differently. Notice that in QM we have the same entity for different interpretations, which are differentiate by other features than the entity. In the case of an electron different interpretations may disagree on parts of the conceptual framework but not on the entities. In this sense, all of them are committed with the same entities, although they differ by the way the entities exist. In this case, there is some sort of ontological commitment, however it seems more elaborate than Quine's first proposal.

Finally, we still could talk about some pluralism relatively to the way one can conceive reality. Reality as a "[. . .] patchwork of laws" (CARTWRIGHT, 1999, p. 34) or as a pluralistic reality[25], however, those views are formulated inside the paradigm that we are trying to avoid. Whether reality exists (if it exists) in a way or another is not a

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[25] See (CHAKRAVARTTY; SUGDEN, 2011).

matter to be decided by the deflationary approach on ontology.

2 METHODS AND APPLICATIONS

“[. . .] all methodologies, even the most obvious ones, have their limits.”
Feyerabend, 1993, p. 23.

2.1 INTRODUCTION

Loosely, instead offering a specific ontology, in meta-ontology we can examine and compare different ontological frameworks. Questions about which ontologies fit in a description of a given physical theory are considered here as meta-ontological problems. In this sense, all our investigations are meta-ontological ones, because they consist in comparing and analyzing different ontologies according to the structural assumptions of the theories.

In this chapter I present different meta-ontological approaches towards the problem of generating and identifying ontologies. In addition, I contrast the different methods examined here with examples from the quantum domain. At the end of the chapter I make a brief analysis of the substantialism as a candidate ontology for the quantum domain.

This chapter is used not to create a well contained methodology for ontology of physics but provide a panoramic view of the difficulties and singularities of ontology in physics. The methodological assumptions made here do not have the pretension of being permanent. Since physical theories came and go, ontologies probably should have the same fate. After all, if some methodology could be extract from this analysis it would be “[. . .] an anarchistic methodology [. . .]” (FEYERABEND, 1993, p. 13).

2.1.1 Interpretation are not ontological models

There is no much agreement among philosophers about how ontology must be undertake on physics. However, many of them conserve common views about the tasks of ontology in physics; some of this views can be condensed in the following quote.

> The third main task for philosophers of physics is the formulation and evaluation of suitable ontologies for specific physical theories. Since — in contrast to general philosophy — these ontologies are always tailored towards a given physical theory, they are often called interpretations. If ’interpretation’ is understood in this specific way, it can be characterized more exactly as a mapping of certain elements of the given theory to entities (e.g. particles, properties, structures) in the world, to which the theory is supposed to refer. (KUHLMANN; PIETSCH, 2012, p. 211)

In this way, the general view about the relations between physics and ontology may can be resumed as following.

(i) i) Ontologies must be tailor-made (FRENCH, 2010);

(ii) ii) Ontologies can be viewed as *interpretations* mapping concepts into entities in the world. (COCCHIARELLA, 2007, p. xv)

I agree that ontologies can (and must) be tailor-made to fit in a given physical theory. However, a so crude positivist/correspondentist[1] approach that pictures ontology as a translator of the concepts of the theories towards the world is a misleading idea. Clearly, according to our deflationary approach, this is a ill-placed perspective that misunderstand the real role of material ontology, and, consequently, commits an error by taking external and internal tasks of ontology as the same. Additionally, we can say that this kind of interpretation, and the traditional notion of interpretation in QM[2], fail for being committed with all sort of realist assumptions. The former fails because assumes that there is a transitive relation between phenomena and ontology. The latter cannot even be considered an ontology since it goes towards the phenomena, being motivate mainly by the realist assumptions of physicists. Obviously, this assumptions are well placed and might be considered in philosophy of physics, however, they are not ontologies working as meta-conceptual frameworks based on categorial analysis. Actually, interpretations are part of the domain of analysis the ontological models; they are not ontological models. Interpretations as Many-Worlds, Many-Minds, etc. may be conceived as specific theories for QM[3] such as those formulated by Heisenberg, Schrödinger, Bohm, etc.. An example will give sense to what I am affirming here.

The case of Many-worlds interpretation (MWI) is an emblematic case of an interpretation for QM. Actually, Everett has called it a “meta-theory” (EVERETT, 1957, p. 454) for QM, since it is based on the formulations of Heisenberg and Schrödinger.

Roughly, Everett's main idea was to create a quantum theory in which the observer could be included in the measurement process. Such aspect is not represented in Dirac-von Neummann formulation of QM. Basically, in standard QM the observer is considered as external to any measurement, leading to the inclusion of the projection postulate. The projection Postulate or Collapse Postulate is conceived as the connection between experience and experiment. In this sense, QM does not represent the observer in the formalism. This approach is know as “external formulation” of QM.

Everett's proposal was to represent both the observer and the system in the formalism. To achieve this he changed the standard formalism by introducing a new element in the formalism called “relative state”. In standard QM the Projection Postulate gives an absolute state after a measurement, whereas in MWI to any state a_i there is its relative state aj, and vice-versa.

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[1] For a similar critique against the positivist perspective see (DE RONDE, 2017).

[2] See (JAMMER, 1974, Introduction).

[3] Peres advocates the same view. See (PERES, 2006, p. xxi).

Put simply[4], in QM a compound system S composed by two subsystems, S_1 and S_2, can be reduced to those subsystems. In Hilbert space formalism it means that the total system $\mathcal{H}$ can be decomposed in its subsystems $\mathcal{H}_1$ and $\mathcal{H}_2$. Consequently, a subsystem never can represent an absolute state once one is always relative to the other. Only the total system can have an absolute state, this absolute state is conceived as a superposition of the eigenstates. This picture is the basic picture of a superposition in QM as defined in the Dirac-von Neummann formulation.

From here Everett introduces the observer in the formalism. In order to include the observer O Everett writes the observer as a state vector $|O\rangle$. When $|O\rangle$ observes that a system S is in a state $|a_i\rangle$, the observer must record the state to secure new measurements. Such "memories"(EVERETT, 1957, p. 457) are represented by writing down the state in the observer which gives us $\left|O_{[a_i]}\right\rangle$, where $[...]$ denotes the observer memory. After each measurement a new element $|a_j\rangle$ is added to the memory of the observer, these elements are written in a temporal line inside the observer as $\left|O_{[a_i...a_j]}\right\rangle$. So, before a measurement the total system can be write as:

$$|S+O\rangle = |a_i\rangle \left|O_{[...]}\right\rangle$$

After the measurement of S in an eigenstate a_i we obtain:

$$|S+O\rangle = |a_i\rangle \left|O_{[a_i]}\right\rangle$$

This means that the observer records a_i without the system enter in that eigenstate. The same goes for the entire superposition which can be write as follows:

$$|S+O\rangle = \sum_i^n c_i |a_i\rangle \left|O_{[...]}\right\rangle \rightarrow |S+O\rangle = \sum_i^n c_i |a_i\rangle \left|O_{[a_i]}\right\rangle$$

Note that each measurement is recorded by the observer, however the system do not enter in a specific eigenstate; the superposition continues. What happens is that the observer observes the values at each state in superposition as part of the system. "There is no place to stand outside the system to observe it. There is nothing outside it to produce transitions from one state to another." (EVERETT, 1957, p. 455) Additionally, since each state is orthogonal to the other the observer can measure a state only relatively to other state, what makes them *relative states*.

Properly, I am not discussing whether Everett's proposal is effective or not. This is not the kind of study that is being made here; what is important is that Everett's meta-theory for QM is clearly a formulation for QM. Notice that since Everett's theory is a formulation, it can be submitted to the first underdetermination as discussed before. Clearly, one could develop an ontology for Everett's formulations, and it really

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[4] See (FREITAS; FREIRE JR, 2008), (EVERETT, 1957).

occurred. Several years after Everett's published his work, Hugh DeWitt proposed an *interpretation* to it[5].

According to DeWitt, after each measurement the universe split into coexisting noncommunicating (ortogonal) new universes. Since the observer is splitted among the universes and is restricted to only *its* own universe, it cannot communicate with other universes. As a result, there is no absolute observer outside the total universes. DeWitt's approach gained much attention in the sixties and continues to be very famous, however it lacks of formal links with the formalism of QM.

After all, it is clear that such "[. . .] ontological charges [. . .]" (FREITAS; FREIRE JR, 2008, p. 12) were added after the original formulation of the theory. Actually, "DeWitt was the first to present Everett's theory in print as involving a metaphysical committement to many worlds." (BARRETT, 2011, p. 278, note 1)

After all, DeWitt's MWI is an interpretation for Everett's own interpretation and does not hold as a real interpretation for QM, being just an "[. . .] application of 'classical' modes of thought to an inherently 'quantic' formulation" (BEN-DOV, 1990, p. 829). Clearly, MWI is not an ontological model as we defined before. In this way, we could say that, in fact, DeWitt's MWI is really just an *interpretation* for Everett's interpretation for QM.

One last remark. As I said above, interpretations cannot be ontological models. Interpretations are under the scope of the first underdetermination, and, according to the deflationary approach, they do no belong to the MU and cannot be considered ontological models for QM.

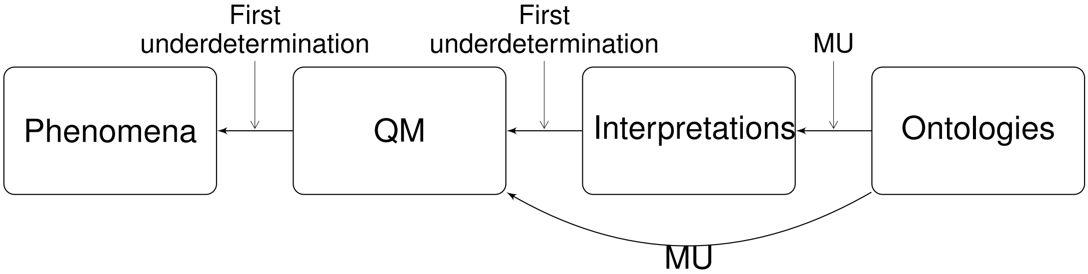

Table 4 – Ontogical models, interpretation, QM and phenomena

As we can see both QM and its interpretations may be the object of ontological description. Interpretations in QM are not ontologies, they are theories *per se*.

2.1.2 Categorial analysis

Categorial analysis is an attempt to make an "[. . .] inventory of reality [. . .]" (POLI; OBRST, 2010, p. 2) by means of some specific ontological categories. To find and to

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[5] It is important to say that the name "many-worlds" was coined by DeWItt and not by Everett.

describe those categories is conceived here as a task under the scope of the internal meta-ontology. In some sense, all philosophers that have dedicated some pages to the theme of ontology have crossed with categorial analysis at some point. As a simple example we could take the Aristotle's categories; a set of ten categories that should describe all entities that exist. Kant himself has suggested twelve, while, for instance, Schopenhauer suggested just three.

Furthermore, contemporary categorial analysis has gained special attention when it started to be applied to computation, information theory, and so on (POLI; OBRST, 2010). While in those cases the number of categories is always increasing, specially with the inclusion of levels of ontology, in philosophy a large number of mono-categorial approaches has emerged.

The ways by which the categorical analysis can be implemented are various, and to choose one of them involves a clear cut of the domain of description in a ontology. In the case of physical theories the way one can make an ontological description may vary according to the methods at hand.

2.1.2.1 Formal ontology

There is a traditional way to divide the tasks assigned to a reasonable ontological examination. Basically, as proposed by Husserl in his *Logical Investigations*, ontology can be divided into formal ontology and material ontology.

Material ontology is any structured set of essential categories that can be used in the description of any entity or relation of a given domain of knowledge. By essential one means two things: First, essential denotes features of those categories or relations that cannot be changed or vanished without change the domain itself. Second, essential means that those categories and relations define the domain as whole, however the categories and the relations are not entities, what makes them free from being confused with any particular relation or entity in the domain. “[T]hey do not add anything to being” (SMITH; GRENON, 2004, p. 287).

To give an example, the particular event of an apple falling from a tree can be described by many categories depending on what one intends to consider essential in such a case. In this particular scenario, an apple can be viewed as a particular entity and be described as a *concrete object* in both a *temporal* and a *spatial process*. If we wanted to know more about what happened at the beginning of the fall, then we could ask for the relation between the tree and the apple, what could be viewed as a parthood relation. On other hand, if we asked for the causes of the apple's fall, then we would need to specify the causes. The causes themselves could be various (gravity, wind, death tree [malnutrition], and so on). Additionally, we could ask for the falling process, it could be examined as a whole or we could be looking for specific instants of time (events). Now, if we take the *falling apple* example from the perspective of a specific domain like physics or botanic, we will note that different aspects are considered in accordance with each of those domains (language-games). This way, the falling process might be described by different categories.

In turn, *formal ontology* is the study of the categories and relations without reference to any specific domain. Essentially, formal ontology operates as a *characteristica universalis* (COCCHIARELLA, 2007, p. 4) by examining what are the essential features that different material ontologies can have in common. Thus, formal ontology seeks to find formal relations that "[...] can obtain between entities of distinct ontologies." (SMITH; GRENON, 2004, p. 287). For instance, the relation substance-accident is always defined in a relation of dependence.

> Substances and accidents are nonetheless radically different in their ontological makeup. Substances are that which can exist on their own, where accidents require a support from substances in order to exist. Substances are the bearers or carriers of accidents, and accidents are said to "inhere" in their substances. These relations between substance and accident will be defined more precisely in what follows in terms of the concept of specific dependence. (SMITH, 1998, p. 22)

Formal ontology searches for the essential commonalities among different categories in different material ontologies; this is made by ignoring the peculiarities of each category. In this sense, material ontology works as a "model" for specific domains, while formal ontology acts as a meta-ontological approach to those ontologies by finding the categories and relations that are presents at any material ontology.

2.1.2.1.1 SNAP-SPAN ontologies

Grenon and Smith (SMITH; GRENON, 2004) make extensively use of the methods of categorial analysis via formal ontology to trace, as they say, a "cornucopia" of categories[6]. They follow the distinction presented in the last section to speak not only about specific cases connected with ontological categories from material ontologies, but, primarily, to propose a categorial analysis along the same lines of formal ontology. Grenon and Smith claim that is possible to find a common core between different ontologies or, according to the authors, perspectives [7] by analysing the formal relations among different ontologies.

Essentially, Grenon and Smith divide the entire range of ontologies into two classes of entities. (SMITH; GRENON, 2004, p. 283). On one hand, we have SNAP ontologies, which deals mostly with *continuants* existing at some instant of time. On the other hand, we have SPAN entities, which are *perdurants*, and, as such, they are

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[6] For the main motivations for their approach see (ZEMACH, 1970).

[7] Perspectivism is the view that reality is only achievable by means of different perspectives. See (SMITH; GRENON, 2004, p. 279).

continuously extended in space and time. The most simple example offered by them is someone and its life. A particular person is a SNAP entity enduring through time, whereas the life's person is perdurant what makes it a SPAN entity.

> The entities recognized by SNAP ontologies are marked by the fact that they: – enjoy continuous existence in time, – preserve their identity through change, – exist *in toto* at every moment at which they exist at all. SPAN entities, in contrast, – have temporal parts (or they are instantaneous temporal boundaries of entities which have temporal parts), – unfold themselves phase by phase, – exist only in their successive phases. (SMITH; GRENON, 2004, p. 283)

Here is not the place to analyze all kinds of entities presented by Grenon and Simons. Thus, I will just present the partial framework suggested by them to illustrate how both SNAP and SPAN ontologies can be viewed.

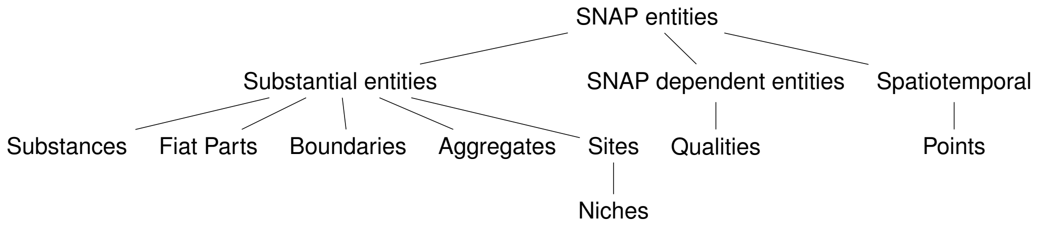

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Table 5 – SNAP ontologies (Grenon and Smith)

SNAP entities are the entities that can be involved by some particularization in terms of properties or relations (things), or in terms of well determined regions of space (lines, surfaces, etc.), or even indexation in time (a person at specific instants of time). In turn, SPAN entities are more dynamical. SPAN entities evolve continuously in time.

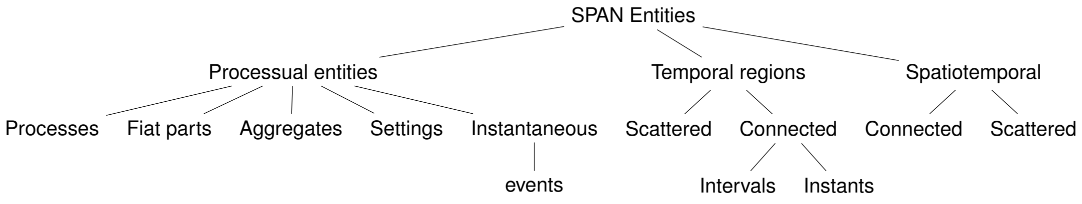

Table 6 – SPAN ontologies (Grenon and Smith)

The main idea with the division is to illustrate that even opposite categories in opposite ontologies can have a formal core based on formal relations. According to them, to identify and to describe such relations should be the main task of formal ontology. Consequently, SNAP and SPAN ontologies are find in diametrical positions, however preserving commonalities from the point of view of formal ontology. Grenon and Smith are very clear on this point. “No SNAP entity is ever a part of any SPAN entity and vice versa” (SMITH; GRENON, 2004, p. 282). Following this view, based on characterizations of space and time it becomes possible to divide the entire range of ontologies.

The formal relations are important because they permit to understand how is possible to deal with different entities from different domains and still obtain formal commonalities. According to them, formal relations can have arity, directionality of the relation, signature, and so on.

For example, a $\langle SPAN_i, SPAN_j \rangle$ for $i < j$ is a relation between SPAN entities at different instants of time i and j. On the other hand, $\langle SPAN, SPAN \rangle$ denotes, for instance, a simultaneously relation. Another example could be the relation with signature $\langle SNAP\ independent, SPAN \rangle$. In this case we could have a *participation relation* which is also a dependence relation. For instance, a runner participating in a race would be a case of an entity that is *SNAP independent* by itself in a process in which she participates, the race.

Various possibilities are presented by Grenon and Smith. Here we can only outline some of them. Although the authors applied their proposal of a formal ontology for several cases, none of the examples furnished by them are related with situations of the quantum domain. For this reason, I would like to propose the use of their scheme to analyze a possible case from such a domain.

Take the case of the non-relativistic Schrödinger wave equation, which provides the linear dynamical evolution of a physical system in QM[8]. During the (deterministic) evolution of a physical system we clearly have a SPAN situation. Conversely, after the measurement, with the wave function collapse[9] we obtain a SNAP situation. What could be the formal relations underlying this situation? Obviously, the wave function collapse has a *direction* that goes from the evolution, which is SPAN, towards the collapse itself, which is SNAP. Both give us a relation with a specific direction; $\langle SPAN, SNAP \rangle$. From that we have at hand the kind of entities and the direction of the relation. What could be the kinds of relation at stake here? Well, it seems that the collapse itself already presents a *dependence* relatively to the measurement process. After all, without the measurement the collapse do not occur, and, in this sense, the dependence is defined by some kind of a *causal relation* between the measurement and the collapse. In turn, the evolution also presents some kind of dependence. The relation between the wave equation and the possible outcomes of a measurement is non-deterministic, and it is so because the Born rule establish that we can only get the probability to obtain a given result after the measurement. Notice that the non-deterministic feature of the equation is due to a superposition of eigenstates before the measurement. In fact, the superposition is still based on some kind of relation[10], however this relation is not a causal relation, it is a part-whole relation. In this sense, the superposition arises

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[8] See Appendix B, Section B.0.1.2.

[9] As usual, we follow Dirac-von Neumann formulation.

[10] See Chapter 3, Section 3.4.1.4.

as whole whose parts are the eigenstates, and, as any part-whole relation, it is also a dependence relation. Notice that, even being different aspects of QM evolution and collapse can be viewed as sharing common structural features related to the ontological aspect of *dependence*. As a result, we might say that the SPAN-SNAP approach, as an example of categorial analysis, can provide profitable results for the ontological analysis of this case in QM.

In conclusion, it seems possible to conceive categorial analysis applied to physical theories as an important tool to compare and analyze different ontological candidates for the quantum domain. However, as we will see in the next chapters, several philosophers of physics, dealing with the specific problem of defining ontologies for QFT, neglect the wealth of options that categorial analysis offers to the examination of the physical theories.

2.1.3 Toy model approaches

The predilection that philosophers have for examples using chairs and tables is a well-known fact, however, more than a obsession, philosophers for the sake of simplicity (or not) always go for the most simple examples. This is not a problem, because we know that when Aristotle takes “Socrates is a musician” as an example, he is not interested by Socrates or any kind of music but just for the examination of the ontological categories at stake in that case. In general, philosophers interested by metaphysics and similar themes use the same kind of examples. In this cases, the choice for a preferred kind of examples goes beyond the simple exemplification and tries to act as a justification for some philosophical approach. In this cases, the philosopher is trying to justify her approach by what we could call a *toy-model example*.

Toy-models are idealized experiments in physics that simplify complex situations in order to make sense of some possible experiment. Mainly, toy-models are used by physicists to justify theoretical assumptions that have no empirical validity or cannot be carried out yet. Generally, toy-models do not correspond to any experiment. For example, AQFT is a physical theory that has its empirical meaning justified by means of toy-models, even if it is not an empirical theory at all.

In certain extent, this procedure is also a common practice among contemporary ontologists[11], including those interested by physics, however things seem to go differently for them[12]. As we know, when one wants to speak about ontology of physics, this one is interested by some specificities of the entities considered by a specific domain of physics. However, the ontologists interested by those themes have difficulties to abandon the everyday examples in favor of examples more alike with the empirical

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[11] See Chapter 4, Section 4.5.0.1.

[12] Clearly, I am not saying that everyday objects are more simple to describe than those from physics, actually they seem much more complex.

content of the theories. That is why I call this kind of procedure a *toy model* approach in ontology; the act of making use general examples from everyday dealing to give sense to ontic aspects of specific theories, in our case, the physical theories.

Obviously, such practice can be well constructed and lead to positive results, however, it is common to ontological approaches lack of meaning when contrasted with the theories themselves. Consequently, the main problem with toy-models approaches is that they are tailored to give sense, primarily, to everyday objects. The problematic outcomes from this kind of approaches is not necessarily based on a confusion between domains of analysis, but in the assumption that there is a privileged domain of investigation. This kind of methodological geocentrism in ontology is characteristic of ontologies projected onto the idea that there is an ontological uniformity among domains. Formal ontology, as imagined by Husserl, was devoted to such idea, looking for common ontological relations along different domains is just look for such uniformity. Clearly, the ancient philosophers like Aristotle, have made the same move by seeking for wide ontologies able to describe the entire reality with some set of ontological categories. However, they do not had have at their disposal all scientific knowledge that we have today at hand.

For instance, this is the case of Keith Campbell and his trope ontology (CAMPBELL, 1990). His view is that tropes can be used to describe any entity at any domain, including those entities from physics, however he is not so effective in trying to make sense of many elements of physics, including “fields”.

According to him, tropes are the fundamental constituents of reality; and fields, electromagnetic fields, quantum fields and, even tensor fields from General Relativity are considered to be tropes of some kind.

> The particles, from the point of view, are thus derivative individuals. They are complexes, superimposed zones of intersection of the flickering and transforming values of the basic underlying fields. The patterns of the dance in which particles combine, divide and decay are created, according to field theory, by the restless shuffles and re-shuffles of the eddies and vortices of these interpenetrating, space-and-time-filling, thin particulars, the field tropes. (CAMPBELL, 1990, p. 146)

Campbell’s advocating idea for a trope theory of fields has two main problems. First, he does not present any definition of a trope that can effective be linked with the definition of a field. In fact, there is no attempt in this direction, only holistic movements to make sense of his proposal. The second problem is that what he indicates as being a field is different from what physicists and mathematicians could define as a field. The following quote helps to understand this problem

“All basic tropes are space-filling fields, each of them distributes some quantity, in perhaps varying intensities, across all of space-time” (CAMPBELL, 1990, p. 146).

Clearly, fields are not space-filling fields, although they are grounded on a base space[13], which is in physics the spacetime structure. It seems that Campbell is identifying tropes with the values of the fields and not with the fields themselves. On the whole, Campbell does not give any formal definition of what he means by a field (any of them)[14].

Finally, notice that I am not defending the idea that ontological approaches must be circumscribed to specific domains, my point is that the several difficulties faced by ontologists in physics is a result of the conceptual load carried by ontologies with universal pretensions. It would be quite positive whether ontologies could give ground for different domains having the same ontological frameworks, however, much of the ontologies fail in that task.

2.1.4 Problems with metaphysical equivalence

A different way to deal with the problem of comparing ontologies or to define what are the most adequate to perform some ontological description is by means of metaphysical equivalence. Metaphysical equivalence can be defined in many ways (BENOVSKY, 2016, p. 3-4), here I only present Benovsky's proposal for a metaphysical equivalence based in pragmatic aspects of the metaphysics (ontologies) according to their applicability. For him, two or more "[. . .] metaphysical theories are equivalent if they do the same job in the same way [. . .]". As I pretend (negatively) to illustrate, such "definition" can be undermined depending on specific domains. To this end I repeat here the same example used by Benovsky in his book *Meta-metaphysics: on metaphysical equivalence, primitiviness, and theory choice*.

According to him, by choosing two apparently opponent metaphysical theories one can compare then by demonstrating that the two accomplish, or not, the same theoretical purposes. In his main example he analyses the debate between Bundle Trope Theory (BTT) and Substratum Trope Theory (STT), proposing that, although structurally different, both theories are metaphysically equivalent since they do the same job. Here I briefly reproduce his arguments.

STT sustains that any entity is composed by properties and a substratum from which this last one acts as the "glue" for the properties. For instance, a specific entity like a chair is, according to this view of the matter, just a bunch of properties tied together by its substratum, which does not only puts everything together but provides one identity for the chair by making it "this" chair. Conversely, in BTT there is no substratum, just properties tied by a relation of compresence in order to make up an entity. According to Benovsky (BENOVSKY, 2016, p. 8), both theories can be viewed as equivalent since, even with different conceptual meanings (compresence and substratum), they

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[13] See Chapter 4, Section 4.3.1.

[14] See (SCHNEIDER, 2006, p. 10-12).

play the same theoretical role by working as "[. . .] a unifying device, a device that takes properties to make objects." (BENOVSKY, 2016, p. 7).

Additionally, he presents several "objections" against the equivalence between STT and BTT, however all of them leads to the conclusion that both theories are equivalent since they do the same descriptive "job". According to him, both have a unifying device that "glue" the properties altogether and gluing the properties is all that matter after all.

It is clear that the context where Benovsky applies his approach is based on a closed context where all the examples refer to everyday entities. But, could his characterization of metaphysical equivalence be applied to physics without restriction?

In this sense, I would like to oppose STT and BTT to an example already used by Simons (SIMONS, 1994). Simons proposes his own trope theory called "Nuclear Trope Theory"[15]. The Nuclear Trope Theory[16] (NTT) still is a STT, however with a different unifying device. Put simply, in Simons's proposal tropes are arranged as properties around some nucleus, however such a nucleus has just a structural role that can be undone if the entity cease to exist or can be changed if the entity suffer some modification. The idea is that an entity does not need a ill-defined category as a substratum to play the unifying role. It is only necessary that essential and non-essential tropes behave in a structural similar to a substratum. Simons's main idea is to introduce a relation of dependence in the theory to give structural drive for tropes. In this respect, NTT is superior to its siblings from BTT.

On other hand, if we follow Benovsky's metaphysical equivalence criteria, it seems that the situation does not change much in the case of NTT because supposedly we could still use STT in place of NTT.

Nevertheless, things do not go that way. Simons proposal is set up for a specific case; the case of a superposition in QM. For now we just need to say that during a superposition of two electrons we cannot say which one is which. Actually, neither is possible to say which electron is which before nor after a measurement (FRENCH; KRAUSE, 2006, Chap. 4). Both entities are "souped" as a whole in a superposition, which is also a quantum state. Simons's explanation is that before and after the entanglement the tropes (properties) of each electron are tied together by a nuclear structure acting in the same way as a substratum (substance), however during the superposition the tropes are untied to enter in a superposition.

The explanation gave by him is that during the superposition of two electrons the tropes of each electron are untied to become a third entity; a superposition. After the measurement the tropes are tied together to become two electrons again.

On other handever, if we rely on the STT we will be unable to represent such

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[15] Benovsky quotes an extract of the paper where Simons presents his theory, however, Benovsky does not address any concerns towards the issues that we are pointing out.

[16] See Chapter 3, Section 3.4.1.

a situation. In STT the unifying device is defined in a "[. . .] primitivist [. . .]" way (BENOVSKY, 2016, p. 7), whereas in NTT it is defined in terms of dependence relations between essential and non-essential tropes. Additionally, STT is based on the own notion of a substratum and cannot afford a disruptive notion of a substratum as that from NTT. How could be possible to say that before a superposition two electrons have two different[17] substratum and then one (the superposition), and then two substratum again (measurement)?

Notice that before and after the entanglement the nuclear relation plays the same role as the compresence what makes Benovsky correct on this point, however during the superposition the substratum approach is unable to provide a reasonable description of the situation.

After all, we still could argue for a substantialist interpretation of the case, and Simons agree on this point. If we assume the superposition as an entity on its own, then we could say that the superposition is a substance. In this instance, it is possible to assume that before, during and after the superposition we have a substantialist interpretation. However, it does not entail that the STT could provide a structural approach as that from NTT.

In conclusion, the substratum category does not do the same job as the NTT in describing a superposition. It seems that the metaphysical equivalence between STT and NTT is just valid in some specific contexts as those from everyday examples (toy-models) used by Benovsky. In my opinion, Benovsky's error is that he sees the unifying devices for STT and BTT as internal to the ontologies, however, they are not. Clearly, substratum and compresence are structural features independent from the factual examples presented by him, however the way the unifying devices work is totally dependent on the actual domain of description. Notice that Benovsky is basing his proposal on common sense examples of everyday entities, and all his justification for the metaphysical equivalence between different metaphysics comes exclusively from that domain. On other hand, Simons is contrasting the ontologies against examples from different domains of description, such as QM. By doing that he becomes able to structure a new unifying device which is not equivalent to the substratum device. In this way, to tie together an entity is something that is relative only to a specific domain. After all, the question that Benovsky is not doing is: from where do we get the unifying device?

There are plenty features that need to be taken into consideration in answering this question. As showed by Simons's, in physics the requirement for unifying devices must come from the theories themselves. Thus, to ask for the unifying device that tie together the entities of an ontology involves much more than what Benovsky is

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[17] Here I am neither discussing the strange situation that two indistinguishable entities could be distinguished by means of a substratum. For a discussion on the matter see (FRENCH; KRAUSE, 2006, Chapter 1).

presupposing.

2.1.5 Falsifiability

In some sense, what we continuously see among ontologists is an attempt to decide between "bad" and "good" ontologies. Some of them try to decide between ontologies by recurring (allegedly) only to the ontologies themselves (BENOVSKY, 2016); others seem to be trying to do the same thing by comparing the ontologies with specific situations or domains (SIMONS, 1994); some still try to create ontologies to fit them into the specific description of the domains; some more adventurous suggest just to take the ontological categories that are conveninent for the job and forget the rest (*Viking approach*[18]). In this sense, ontologists are generally testing their ontologies and, consequently, enhancing them. Such a pragmatical approach is very similar to the Popperian falsifiability. This "[. . .] metapopperian [. . .]" (ARENHART, 2012) view about ontologies has already been set, however, it presents several limitations and it is not free from many of the issues discussed before. Clearly, the adepts of such a view are methodologically correct. Since scientific theories are falsifiable why the ontologies associated with them would be not?[19]

Here, the way one could implement falsifiability over ontologies is what requires more discussion.

Arenhart (ARENHART, 2012) is particular concerned with this problem. According to him, there are two main senses of ontology: the traditional one and the naturalized one. The first one he identifies as an *a priori* ("universal" or "absolute") approach to ontology, while the other he interprets as a scientifically oriented ontology in the Quinean sense. This last one he links with a third meaning based on the relation between logic and ontology. Here we consider just the first two. Arenhart claims that ontology in the traditional sense must provide the possible categories that a naturalized ontology must use "[. . .] to classify the items associated with a scientific theory [. . .]" (ARENHART, 2012, p. 341). To this last meaning of ontology he attributes the task of providing a way to decide between competing ontologies in the scientific domain. According to him, the way it is done is negative because the comparison between the possible candidates and the theories can just provide a way to eliminate the most inadequate candidates. But, why he arrives to such a negative conclusion?

It seems to me that Arenhart does not attribute a positive role for this procedure because he denies that scientific theories may provide positive contents for the formulation of the ontologies to be associated with them. In this way, I would like to address some remarks on this point.

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[18] See (FRENCH, 2014, p. 50).

[19] An analogous suggestion is made by Smith and Grenon, both defend the idea that an ontology might be changed according to the scientific development (SMITH; GRENON, 2004).

Although aware of the several meanings given to the word “ontology”, Arenhart divides ontology into pure study of categories and naturalized ontology based in Quine’s commitment criteria. With this choice he lumps together all traditional approaches to ontology in just one bag. This makes him to loose the traditional line that divides formal ontology from material ontologies. Basically, he replaces the role traditionally attributed to material ontology by the naturalized ontology that he defends, however, this is not just a change of labels.

Arenhart takes Quine’s commitment criteria as a divider between ontologies that fit into the ontological description of scientific theories and those descriptions that do not do the job. The problem in getting Quine’s criteria is that it is about the scientific theories and not about the ontologies. Quine is concerned with the conceptual framework with which the theory is committed, not about the ontological categories used in the ontological description of the theories, and, apparently, Arenhart is aware of that (ARENHART, 2012, p. 344).

In my opinion, the major problem Arenhart’s proposals is the consideration that “[. . .] scientific theories does not provide us with information about the relevant ontological categories they must be committed with, they are simply not made for that purpose” (ARENHART, 2012, p. 354).

Obviously, and our argumentation goes in the same direction, theories are not about ontologies, however, that scientific theories do not have the purpose to generate ontologies does not imply that they do not provide us with the means to generate such ontologies. Well, I frankly believe that physics (science) in general offers the necessary tools to the generation of ontologies. In this sense, I would like to give an example in favor of this idea.

A first approximation towards the assertion above is by means of the so-called “nomological objects”. Even though tables and stones are, in some sense, natural kinds like electrons and positrons, both classes of objects are very different. While tables and chairs are everyday objects, electrons and positrons are objects defined according to the physical theories that describe their properties and predict the phenomena related to them. This why, nomological objects are those whose properties[20] are prescribed by physical laws. “All objects of physics are more or less nomological” (DI FRANCIA, 1978, p. 63). In a more radical way one could even say that some entities considered in the physical theories are just putatives ones. (FRENCH, 2014, p. 182). However, if the entities of physics exist as material entities or not, or even if they could be reduced to mathematical structures, is a matter to be discussed by realists and anti-realists; a debate from which we already have disengaged. Since the entities from physics (its relations and properties) are defined in the theories, it seems possible to imagine that we could do the same with the categories of our ontologies. So, what could be

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[20] See (FRENCH; KRAUSE, 2006, p. 221-222).

the most natural place to look for hints to build up ontological categories than the physical theories themselves? Clearly, physical theories furnish a entire set of tools to accomplish such a task. The tools can be the algebraic and metric structures, groups of symmetries, and so on. Despite those structures being used to define the entities of a given theory, perhaps they can still be used to setting up ontological categories. In the following chapters we will see some attempts in this direction. After all, it seems that ontological categories could also be "nomologically" defined. That is the positive aspect that Arenhart is leaving aside.

For the sake of example, virtual particles[21] in QFT are mathematical devices that explains how some disturbances in the electromagnetic field happens. By "virtual" one means that does not matter what something is or the role it plays in a theory it is not measurable after all (FALKENBURG, 2007, p. 223). The issue is that (perturbative) QFT demands those particles to work properly, even though they never can be measured. In some sense, to exist and to be measurable are at the same level here. Thus, if we apply the equation *measurable = existence* to our ontologies, then perhaps we would have been provided with an existence criteria. As we all know, a criteria for existence is really important for an ontology. In this case, it seems more critical because QFT is committed with the virtual particles in a Quinean sense, however, they do not exist at all. Although they are just disturbances in a field, to make sense of calculations physicists take them as virtual particles exchanged between real particles in the electromagnetic field. In a Vaihingerian sense, it is just as if (*als ob*) they were particles. In this connection, we could advocate for two notions of existence, one is given by the theory in its commitment with the "particles" and the other can be based on the measurement process. How could we achieve this result without looking inside the theories? After all, it seems that physics can furnish some positive hints for the ontologist.

Obviously, if one assumes that the scientific theories cannot provide the necessary elements for the definition of ontologies, then we shall never define an ontology for a physical theory in a positive way. It is like a shot in the dark. However, unlike Arenhart's proposal, physical (scientific) theories seem to provide us with elements that can be used to generate ontologies. Above all, "[o]ntology does not comes free; it demands concepts for representation" (AUYANG, 1995, p. 118). Actually, physical theories provide us with structural features that must be considered in making ontologies. This assumption goes against the idea that (traditional) ontology must provide categories in a *a priori* way, and then to be tested by naturalized ontology.

In conclusion, it is clear that Arenhart is in the right direction by suggesting that ontologies can be falsifiable, however his refuse to indulge the scientific theories with a positive role in making ontologies is too much restricted. If we deny a positive aspect for the theories, then the ontological investigation in science is reduced to an ontological

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[21] See Appendix C, Section C.2.1.1.

Darwinism.

2.1.6 General view

There are plenty meta-ontological approaches towards physics, and here we analysed just a few of them. Those examples helps us to understand how the task of ontology in physics is challenging. Given that, I would like to mention some possible results obtained from the examinations made in the last sections.

(i) Categorial analysis is a powerful approach towards ontology in general and this is not an exception in ontology of physics.

(ii) The recourse to the definitions of space and time of a given theory is not only useful to distinguish the entities of a specific domain, but it is also useful to identify the structures that may be taken into consideration when one is trying to create an ontology for a physical theory;

(iii) The use of everyday examples to give sense to ontologies may lead to mistakes in the ontological description of a domain. It seems that the best way to build up categories is by grounding them on actual examples from the theories themselves;

(iv) Metaphysical equivalence between ontologies depends on the specification of the domain. As showed before, the use of toy-model examples can hide situations where metaphysical equivalence does not hold;

(v) Certainly, provide negative tests to filter the best ontologies for a given physical theory is a useful method; however, it is equivocate to attribute only a negative role to the scientific theories in such a task. In fact, theories can provide informative contents in setting up ontologies.

2.2 READING SUBSTANTIALISM

2.2.1 Substance

The category of substance has been considered by many philosophers as the most fundamental, and this does not exclude philosophers dedicated to the same kind of investigations of ours. In the following pages I would like to make a few remarks on this matter and see how such a category could be fit in the ontological analysis of the quantum domain.

First of all, since the concept of substance is so traditional in philosophy as cumbersome. We are not considering here any divergences about the uses of the concept "substance" or any other correlates such as "essence", "substratum", and so on, whose may be considered synonymous or not according to the philosopher. Thus, even with an entire history of the concept at hand we have decided to follow the most general view about it. Such a view states that by substance we must understand an ontological category that represents something that does not need anything else to exist. According to Aristotle, the category substance can be understood as the cause of the natural things, being indivisible and not predicable of anything else. Additionally, in Aristotle's view, any entity has its own substance, which make it what it is.

After all, substance ontologists may still disagree on what a substance is or how it could be defined, however they do not disagree that any notion of substance is based on the "[...] notion of *ontological independence*" (LOWE, 2006, p. 109). Such independence have provided a privileged place for the substance view throughout the history. Even though with many defenders, substantialism has been criticized in several directions.

At the beginning of his seminal work, *Philosophical Investigations*, Wittgenstein made his famous critique against the ostensive model of language; the idea that reality is mirrored by language. The target of such a criticism is the conception of a reality based on things referred by language; a reality crowded by material objects (FRANCIA, 1986) encapsulated by the word "this" (WITTGENSTEIN, 1953, §10). Even with many other deviations, Wittgenstein's criticism is a massive attack against the substantialist view. Obviously, Wittgenstein has criticized other metaphysical approaches by saying that any metaphysics is just another picture that "held us captive" to the concept of substance (WITTGENSTEIN, 1953, § 115), highlighting that the only way to do philosophy is by making a critique of language. Thus, for him, language would be the origin of any metaphysical misconception. Should we do the same critique in physics?

In fact, analogies between dead cats and probability around process of beta-decay make everything even more confusing when one is trying to give sense to the quantum phenomena. In the same sense, it does not seem to be the best methodological option to insist that substance ontologies must be at the center of the investigations on those matters. After all, why do we still consider the philosophical view imposed by Aristotle in philosophy of physics even when we already abandoned his way to do physics? Perhaps, philosophy of physics should also do its own critique of language. Not only a critique of the ordinary language present in the analogies made by Einstein, Schrödinger, Wigner and others, but also a critique about the physical-mathematical language used in physics.

In addition, the use of the ordinary language in the explanations of many quantum phenomena is the source of many misunderstood. After all, the ordinary language is grounded on the concept of object whose immediate correlate in ontology is the substance concept. Thus, a criticism of the substantialism in the quantum domain demands a critique of the language. I am not saying that the substance category cannot be used in the ontological enquiry carried out here but just showing how such category can lead us to more problems than solutions.

> “The popularity of substance ontology, for example, is not due to its (rather poor), explanatory achievements, but mainly due to the fact that the technical term substance is the categorization of a genus-term of common sense reasoning that we agentively understand particularly well: things.” (SEIBT, 2002, p. 60)

Philosophers may disagree about its main assumptions like assuming a nominalist[22] view or a universalist[23] one, however, some shades of substantialism still resides in their philosophies after all.

It seems that everything is an object for us, and thing-thinking is a fact that transcends all the realizations of the scientific practice. In the end, “[. . .] it is not the world in itself to made up of objects, but that we divide the world into objects [. . .]” (DI FRANCIA, 1978, p. 58). After all, the assumption that everything around us are things is just a convention that make the human adaptation more feasible. However, the development of science has entailed in outcomes that challenge our thing-view about the world. In the end, science has shown that “[a] thing theory is a convention that is not aware of its own conventionality.” (AUYANG, 1995, p. 9) Evidently, the issue of how we constitute reality in an objectified way is a matter that must be take into consideration in ontology of physics, however that is not the kind of study presented here.

2.2.2 Substantialism in the quantum domain

The substance category is still in use. In fact, when it is applied to the quantum case the problems increase in different ways. For instance, the substantialist runs into a lot of difficulties when he tries to explain how an electron can be distinguished from another one (FRENCH; KRAUSE, 2006, chapter 1), or when he needs to describe what happens when we ask for the precise location of a particle in QM.

To deal with the problem of particle indiscernibility the substantialist usually defends that despite two quantum entities, such as two electrons, have the same properties, they are distinguishable by their substance because each one has its own substance. Such a move is very embarrassing since it is not even possible to define any mathematical counterpart in the theory that could fulfill the role of a substance. The problem still persists in the case of a superposition. The substantialist defends that even in the case of a superposition of two or more indiscernible entities, these entities could be identified as different individuals by their substance. The problem is that the theory does not have any formal counterpart that could justify such a view. Actually, if the substantialist view is preserved, then the concept of superposition is jeopardised

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[22] See (KOTARBINSKI, 1968).

[23] See (ARMSTRONG, 1997).

because in a superposition the properties that characterizes an entity cannot be well determined. There is no way to track down the properties of an entity in a superposition, since, ontologically, there is no way to distinguish them during the superposition. The substantialist view goes against the theory itself when she resorts to the traditional concept of substance to do it.

In the same sense, by the uncertainty principle, the precise localization of a particle is not possible to be defined, even after a measurement. As a result, the point-like aspect that classical objects have is lost. (FALKENBURG, 2007, p. 205) Since it seems that substantialism and particularism walk together, it becomes difficult to see how the substantialist could describe such a situation. The problem of substantialism, and particularism, becomes more critical if we look more inside the theory. Usually one may think of localization as given by a particular point, however, as advanced above, it seems not to be the case in QM. Anyway, one could still be interested to know more about the localization as a property of an electron. The problem, more radical yet, is that position as property of an electron does not exist *per se*. In fact, different from what we could initially presume, the scientists make use of specific arrangements that allows the existence of the position of an electron, which is contrary to the idea that the position is something to be discovered.

> After the formulation of Heisenberg's uncertainty relations, the closer analysis of indeterminacy by the discussion of many thought experiments led to a much deeper negative statement: it is not possible to assume that an electron has, at a particular instant of time, any position in space; in other words, the concept of position at a given time is not a meaningful attribute of the electron. Rather, "position" is an attribute of the interaction between the electron and a suitable detection device. More generally, a phenomenon which we observe does not reveal a property of the "atomic object". The phenomenon is created in the act of detection. This fundamental point is somewhat veiled in the standard language. If we say that some "observable" of a quantum object is measured this suggests that there is some corresponding property of the object which may have different numerical values in the individual case and the purpose of the experiment is to determine this value. By contrast Bohr stresses that the measurement result is a property of the compound system of measuring device plus object and that the full description of the experimental arrangement is an essential part of the definition of the phenomenon. Thus, Max Born's probability for the "position of a particle" within some region of space should be understood as the *probability of an effect* if a detector is placed in this region. (HAAG, 2012, p. 294)

Similarly, in QFT the field operators (quantum fields) are defined under spacetime points, however there is no fields values at spacetime points, but just regions around those points (neighborhoods) on which those operator are smeared out (Wightman axiomatization). Thus, "[...] it is not only difficult to define the value of a field at a point, but it is impossible to do so - such quantities simply do not exist." (HALVORSON; MÜGER, 2006, p. 42-43). How the substantialist could deal with this situation? Clearly, he cannot use the same strategy from CM, where values are give to specific points that could preserve particularism and, consequently, to maintain some kind of substantialism. In the case of QFT we are dealing with continuous regions that cannot be reduced to a particularist view. Apparently, more dynamical categories are required in this case[24].

Finally, I would like to talk against the traditional definition of many-worlds (MWI) in DeWitt's terms. Even whether the substantialist chooses an interpretation like (MWI), where the wave function collapse does not hold, the problems remain. Unlike standard QM, in MWI after a measurement of a superposed electron spin, the two possible outcomes, up and down, are realized. However, this is only possible by postulating a different world where the spin value measured in the actual world gets a different value there. Notice that whether we conciliate the substantialist conception with MW, we will contradict one basic aspect of the substance category: substances are not divisible. Even if a substance were divisible, the electron in the actual world would continue to be the same in another world except for the difference in the spin value. Thereby, we have two options: or the substance is the same for both entities or it is different. In both cases we have problems. On one hand, if the entities are the same in two different worlds than we have two entities with the same substance, what goes against the use of substance to preserve individuality. Second, if the substance is different, then the substance is divisible. Additionally, we could rise many questions for the substantialist. How could the substance be the same now that we have two entities? Any of those entities conserve the original substance or these are new substances? Whether they have the original substance, the electron in one world has the original substance and the other not?

As we have seen, the examples above illustrate how substantialism may lead to several difficulties when confronted with situations of the quantum domain. In conclusion, despite substantialism being a fact in the daily life, philosophers still can think outside of that paradigm.

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[24] See (AUYANG, 1995), (SEIBT, 2002).

3 TROPES

> *"What makes a bundle of tropes a bundle?"*
> Kuhlmann, 2010, p. 144.

3.1 INTRODUCTION

After discussing distinct meta-ontological approaches and criticizing, explaining and punctuating certain virtues and vices of such proposals, now we have reached the point of discussing the trope category (EHRING, 2011, p. 15). This unusual ontological tool has gained increasing prominence among philosophers oriented towards physics[1].

Properly, we discuss the trope theory in three moments. First, we present a general characterization of such a category; its motivations and its context of origin. In a second moment, we deal with the uses that have been given to this category in the quantum domain, in particular, we will be dealing with two trope ontologies, one developed by Peter Simons, (SIMONS, 1994, 2002) and the others created by Meinard Kuhlmann (KUHLMANN, 2010). We will pay more attention to Kuhlmann's approach because his proposal is applied in a more extensive way than Simons's original proposal. In fact, Kuhlmann himself argues that his theory is an extension of Simons's original proposal, including not only the phenomena studied by QM but those of QFT too. In the end, we will discuss the merits of these approaches by pointing out both their advantages and their limitations.

3.2 OVERVIEW

The contemporary[2] trope ontology arose in the context of the contemporary quarrel between universalists and nominalists (CAMPBELL, 1990, p. 27). More clearly, the trope theory is a response to the problem of the existence of universals. Thus, while the universalist claims that there are such abstract and crystallized properties instantiated by different particulars (abstract or concrete), the nominalist denies the existence of universals. For the nominalists, the situation is quite clear, only two possibilities are conceived, there are properties in some extent, however they are not universal, or there is no property of any kind, just things. In this last case there are only concrete particulars, whose so-called "properties" are considered, in general, as conceptual abstractions or even as linguistic fictions (*irrealia*). As we will see, trope theory can be understood as a form of nominalism, but this assumption is a sensitive topic even among nominalists

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[1] For a general view on tropes see (MAURIN, 2018).

[2] In a sense, the trope theory is very old and can be traced back to Aristotle and Plato, passing through medieval and modern philosophers such as Ockham, Leibniz, Locke and many others. See (MAURIN, 2018), (SIMONS, 1994).

Therefore, for many practitioners of meta-metaphysics, the trope category emerges as a mediating option that brings altogether both positions. On the one hand, it concedes that there are abstract properties, on the other hand, it concedes that the only entities that exist are concrete particulars. In this sense, tropes are defined as abstract properties.

> “[I]t is not true that there are no properties, only classes of objects. For the classes are classes of objects with properties. It does not follow from this, however that the properties in question are universals. The trope theory is exactly a theory according to which the properties of things are themselves particulars, and there are no universals.” (CAMPBELL, 1990, p. 19)

The outcome is quite clear for the tropist. There are no universals; there are only abstract particulars which compose concrete particulars. In this sense, an entity is described by the several tropes that compose it. These tropes are abstract, whereas the entity is concrete. Different from the universalism, in trope theory one and the same trope cannot be present in the composition of two distinct entities. For instance, if we have a basket full of red apples and take one of them in order to describe it by using a trope ontology, the redness of that apple would be described as a trope. However, if we took another apple, in contrast with the universalist, the tropist will defend that the redness of the second apple is ontologically different from the first one. This occurs because the trope category is totally dependent on its spacetime[3] definition.

> Trope theory is the view that the world consists (wholly or partly) of particular qualities, or tropes. This admittedly thin core assumption leaves plenty of room for variation. Yet, most trope theorists agree that their theory is best developed as a one-category theory according to which there is nothing but tropes.(MAURIN, 2018)

In the following we will present the main aspects and approaches for this theory in order to achieve the conceptual map needed to apply this theory in the quantum domain.

3.2.0.1 Tropes and concrete particulars

The general task of a trope ontology is to describe the particular concrete entities of the world as a composition of tropes. The nature of this composition, as we will see, is what differentiates the various trope ontologies. For this reason we cannot say that there is just one trope theory. In general, “tropists” accept that tropes are abstract properties or particulars given in points of spacetime. The way these tropes are given determines not only the particular entities, but also the relations between those entities.

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[3] In general, tropists do not characterize what they mean by “space and time” or “spacetime”.

So, with the purpose to explain how the entities are composed by tropes, the tropist focuses on the structural and conceptual aspects of this theory. Generally, this task is carried out by a *bundle theory of tropes* which consists in a formulation of trope theory that conceives each trope as part of an entity composed by a bundle of tropes. Actually, this leads to another problem, namely, the problem of answering what concedes unity for a bundle of tropes.

Searching for ways to solve this problem, the tropist fixes the ontological core in the possible situations involving tropes and the entities composed by them. In general, tropists assume that there are at least four types of relations between tropes: relations of co-location, co-temporality, co-presence and similarity[4]. The co-localization relation determines that two tropes can exist in the same place but at different instants of time. The co-temporality relation determines that two or more tropes can exist simultaneously but at different locations. If two or more tropes are co-localized and co-temporalized, that is to say, they are given in the same place and at the same time, then these tropes are bundles that forms the same concrete particular. Such a relation is called the compresence relation. Thus, it is normal to say that a trope theory needs to be formulated in terms of a trope bundle theory. How these bundles are composed is a matter of constant debate among tropists.

In turn, the dispute between tropism and universalism is solved insofar as tropes are always individuated space-temporally. This individuation prevents that exactly resembled tropes compresents in different particulars could be conceived as the same one[5]. Consequently, individuation is a major issue for the tropist and give rise to the most disputed terrain among different branches of tropism. Furthermore, there are plenty tropes theories such as Resemblance Trope Nominalism, Natural Class Trope Nominalism, and so on. In addition, it is necessary to mention that there are mereological approaches towards trope theory[6].

Last but not least, these theories, as always, have other purposes than a specific application as we are looking for. They are dealing with the attacks of the universalist. In addition, they are in a dispute with several branches of nominalism. Some of these theories offer partial solutions for many challenges posed by the universalist. Thus, in the following sections we will focus only on the aspects of trope theory that can directly contribute for our investigations.

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[4] Different formulations of the theory use different names for these relations, such as “resemblance” and “exact resemblance” for similarity, and “coinherence”, “concrescence”, “togetherness”, “concurrence” for the others. See (MORMANN, 2003, p. 130).

[5] This is a problem for the tropist because both tropes and universals give rise to an equivalence class. From the tropist side, the resemblance relation is an equivalence relation giving rise to equivalence classes. In turn, one universal can be instantiated by different particulars, being defined as an equivalence class by its identity relation. To summarize, it is a problem for the tropist that the ressemblance relation entails in an equivalence relation because it could make tropes to crumble into universals (MORMANN, 2003).

[6] For a general view on the matter see (PAUL, 2010), and (MORMANN, 2003) for a formal exposition.

3.2.0.2 Trope Bundle Theories

At this moment, we already know a little bit about the bundle approach, however some additional remarks are still to be made in the next sections.

Trope Bundle Theory argues that any entity is composed by tropes acting as bundles of properties. Put simply, if an object A has *n* properties and k_1, ... k_n are properties of A, then any k_i is a trope composing A, whose unity is assured by some relation of compresence, c_i.

At first sight, we can see some problems here. The first one is that it leads to a "vicious infinite regress" (EHRING, 2011, p. 13) based on the fact that any compresence relation relies on another compresence relation which is not identical with the first one. Ehring himself (EHRING, 2011) proposes that this weakness can be defeated by assuming the compresence as a *self-relating relation* that would close the chain of infinite regress. Whether his solution is feasible is not a matter of concern for us; the structural problem of how a bundle of tropes becomes a particular is our main concerning.

Once more the structural aspect arises. First, it is not clear how or why the compresence relation occur. Since a compresence relation is just one possible relation, what makes that one specific relation occur and not another else is an unclear aspect of this theory. Secondly, unsurprisingly, no one is concerned with specific domains that could provide the formal background for the theory.

3.3 LOOKING FOR GROUNDING

As we have already repeated *ad nauseam*, without paying attention to the structural features of the domain investigated it is very unlikely that an ontology could obtain a clear description of the entities belonging to it. And more, most part of the constraints imposed against this *bottomless ontology* are the result of an unstructured approach. One of the effects of this kind of ontology is the infinite regress. This unwelcome feature is the nightmare of any ontology. The majority of the ontologists believe that this issue is the result of the ontological tools selected by the ontologist. Although many times it is true, sometimes even whether the ontologist changes the categories or ascribes new fresh structural relations to them the infinite regress persists. The resulting question is: How can we stop the infinite regress?

I think that most of the time such a problem is just the result of the lack of attention paid to the background presupposed in the domain in question, and the closure of the infinite regress in some ontology can be engendered just from the formal structure of that domain. The point is that we need to find some formal grounding in order to stop the regress, and more than that, we need that this foundation might act as a catalyst and organizer for the categories. Thus, in the following sections, we are going to deal with the relation between ontologies designed to manage with quantum theories and the formal background presupposed by the latter. But before entering in that battle I would like to expose a trope ontology that exemplifies what we are saying about the grounding problem.

3.3.1 Tropes, phenomenology and the grounding problem

One of the representatives of the trope theory is Edmund Husserl[7] (HUSSERL, 2001), but the theory developed by him, who never used the term “trope”, presents particular nuances and differs substantially from what we could understand by a trope theory. Instead “trope” the term used by him was “moment”[8] and differences go beyond terminology.

First of all, we need to make clear that Husserl forged a mereology in which a whole has its parts classified as *moments* and *pieces* (HUSSERL, 2001, p. 256). Basically, moments are understood by him as parts of a whole that are entirely dependent from the whole, on the other hand, pieces are parts that can be detached from the whole and remain as non-dependents parts from that whole[9]. For example, an apple can be subjected to several actions, we can peel it or extract its seeds, and so on. As a result, its seeds and peel can be conceived as parts that are non-dependent parts of it. They do not depend on the apple as a whole because they are configured as wholes themselves. On the other hand, the red colour and the extension of the apple are also parts of it, but they are dependent from the apple wholeness, they cannot exist as non-dependent parts. Ergo, moments are abstract parts of the apple in a very similar way as tropes. Just to make clear, the simple proximity between Husserl’s mereology and the trope theory is not what motivate us but the key insights resulting from the structural features of such a mereology.

Following our example, even detached from the whole that the apple represents, seeds and peel are wholes by themselves. Therefore, if they are wholes then they have parts themselves which can be understood again as pieces and moments. This kind of situation, as we already know, leads directly to the infinite regress problem, but the Husserlian proposal is remarkable because the mereology proposed by him deals incisively with this problem.

We do not intend to retake Husserl’s mereology in all its extension, just those elements that are crucial to understand his solution for the infinite regress problem, and, at the same time, to offer a well structured ontology as his mereology is. As a result, two main aspects are covered by him: the grounding problem and the structural one.

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[7] For an analisys of the phenomenological features of the quantum domain see (ARROYO; NUNES FILHO, 2018).

[8] See (MULLIGAN; SIMONS; SMITH, 1984, p. 12).

[9] See (HUSSERL, 2001, p. 284).

First of all, we need to say that there are some aspects that distinguish Husserl's proposals from others. First, Husserl has always had a background acting as a catalyst for his ontology: the consciousness. Second, for him, things as universals exist. However, we need to be careful, his option for universals is aligned with the structure of intentionality[10], which holds consciousness altogether as a cohesive structure that provides meaning for our intentional acts.

This cohesive structure is only possible for Husserl by ceasing the infinite regress. In that respect, he provides an ontological apparatus in order to explain his *relation of foundation*. According to Husserl, there is something as a relation of foundation, in other words, certain properties are related to each other in such a way that some of them exist only in dependence with others. Furthermore, some of these properties play the role of a basis for such a dependence relation. Thus, the way by which Husserl develops his theory is by using the idea of dependency instead of a third item that could bind one or more properties into a whole, thus avoiding to resort to a third instance as bare particulars, substances, among other candidates. With this move Husserl closes one door of the room, but many others are yet opened; the main one is about how this dependency works.

In his *Logical Investigations* he dedicates an entire chapter dealing with this problem. Loosely, Husserl's theory, for whom things exist as ideal species which are very much alike with universals, establishes two types of foundation relation. The first is a *weak foundation*, in which an entity A is weakly founded on a part B only if A cannot exist unless B exists. In this case B is said to be a proper part of A. On the other hand, when A is weakly founded on B, but the latter is not a proper part of A, then we can say that A is *strongly founded* on B.

Following on this, according to Husserl, the third element used in several ontologies to seal the ontological leak that the infinite regress causes must be replaced by the dependence relation in order to cement the ontological ground.

3.4 SIMONS

There are two main positions that Simons presents in the trope department of ontology of physics, such views were presented by him at different times by showing divergent perspectives about the uses of tropes in the quantum domain. For this reason, as we shall soon see, the main result is that the trope category is a viable and useful ontological option to make sense of the quantum phenomena (SIMONS, 1994). However, it will be considered by him as a problematic category because we cannot employ this category alone, depending on the domain other categories can be demanded(SIMONS,

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[10] For Husserl it is easy to speak of the redness of the apple and the redness of the door without committing itself with extra-subjective or extra-linguistic instances. After all, he is only speaking of the objective essences that constitute such objects and nothing more.

2002).

3.4.1 Nuclear Bundle Theory

In a paper from 1994, "*Particulars in particular clothing: Three trope theories of substance*", Simons (SIMONS, 1994) proposes a structured ontology of tropes inspired by the Husserlian mereology. His proposal was also conceived as an option to explain some specific quantum phenomena, such as the superposition problem and its relation with the identity problem. With this aim Simons examines the ontology of tropes proposing a new categorial structure for this ontology.

Simons's ontology, much more than a refinement of the trope category, is an attempt to elegantly unify substrate theory with trope bundle theory. The result of this alliance he called *nuclear trope theory*. In this formulation he seeks to simulate a substrate by means of a bundle of essential tropes acting as a gravitational core of an entity. The intention of this maneuver is to condense certain properties, understood by him as tropes, as if they acted as a nucleus that characterizes each entity. In what follows we try to clarify the motives and the ontological structure that Simons proposes in order to obtain such an ontology.

3.4.1.1 Looking for grounding

According to Simons, the main problem faced by trope theory is the lack of an internal structure that might describe how dispersed tropes emerge as a single cohesive entity. In this sense, the question is: How to defend a theory of tropes without describing entities as just a bunch or collection of random properties? Simons's answer is important because he attacks the structural issues involving the trope ontology, thus avoiding traditional solutions for this problem in order to find the gravitational core of any entity. To achieve this task he rescues traditional categories and try to reformulate them by means of his trope theory.

In attempting to solve the aforementioned problem, traditional metaphysics has largely resorted to the concept of *substratum*. So, as Simons would say, *substratum* acts as the "glue" of all properties instantiated by a certain object. However, *substratum* theories are heavily criticised by their ontological vagueness. Furthermore, its close relationship with the theory of universals makes it become a primary target of several criticisms posed against the universalists.

The substrate basing an entity would be a bare particular, i.e., a *thin* particular present in all entities, but which has no properties (universals, tropes, etc.) itself. "They are nothing but a pincushion into which universals may be poked." (SIDER, 2006, p. 1) In this way, the bare particular would be the ontological aspect that would define a certain entity in a univocal way. This strategy, much used in traditional metaphysics, has until today an extensive use in ontology, however, it entails more loss than gains.

In particular, the theory of substrates maintains an intimate relationship with the theory of universals, where the substrate is understood as the core that unify the properties present at a particular. This situation coupled with the fact that no property is present in the bare particular, preventing it from being taken as the object of knowledge. We never really know what a substrate is. Not to mention that even if we vanished all properties from some entity the bare particular would not cease to exist. After all, there is no final property that can be excluded from its constitution. Basically, the theories of substratum are based on an ontological conception that is approximate to the *haecceity*.

The problems presented by Simons against the theory of substrates are incisive and reveal how this category does not clarify any point about the constitution of any entity. This is a very strong negative aspect of this theory and applies not only to universals understood as properties, but also to tropes. Basically, the proponents of this theory cannot explain how those properties or tropes are held together as an entity.

Simons aims to develop a trope theory that preserves the advantages of having something acting as a *substratum* providing an ontological basis for the existence of a certain entity, but without the lack of meaning presents in the traditional theory. Thus, he argues that it is possible to take essential tropes as a structured nucleus or kernel for any entity. Basically, the idea is that the nucleus of an entity forms something like an individual essence that simulates the concept of substrate. This task will not be easy and Simons relies largely on Husserl's ontology.

According to Simons, what Husserl aims to do is to find a primitive relation that grounds other relations and properties (tropes). If it would be possible to establish the most primitive and basic relations that are responsible for the constitution of entities, then it would be possible to generate an ontology that did not imply in some kind of infinite regress.

For Simons, Husserl's proposal is very effective but does not deal with all possible entities and foundation relations that may be required in a complete ontology. For example, as Husserl accepts the existence of species (ideal objects) in a sense similar to that of universal, he ends up not dealing with the distinction between types of foundation or, the same, between types of dependence. According to Simons, we can deal with dependency in two ways.

For example, when we deal with dependence between types of species like colors and colored objects, we are not dealing with the specific objects or properties but only with the dependence between those species. In contrast, when we deal with specific colors and objects, as *this* tone of red or *that* entity, then we are dealing with *de individuo* dependency. This examination does not exist in Husserl's proposal and demonstrates how the Husserlian reading may be limited to the problem of the foundation relation. Hence, Simons will extend the Husserlian proposal aiming at a more comprehensive ontology that can encompass different entities in different domains, especially the scientific one.

What Simons seeks is an extension and an improvement of the trope ontology and, at the same time, to solve the problem of the constitution of the entities. Of special interest will be the idea of Simons to extend coherently the theory of tropes to the quantum domain, since, according to him, “[i]t is a good test of a such a would-be scientific ontology to see whether it can be smoothly applied to areas outside the medium-sized world with which we are familiar, in particular to the objects of advanced physical science.” (SIMONS, 1994, p. 19)

3.4.1.2 Primitiveness and Foundation

After presenting the Husserlian mereology, Simons presents his own ontological proposal. First of all, we must say, following Simons, that his ontology deals not only with everyday objects, as usual, but, also, with the presupposed entities existing in different scientific domains. With this task in mind, he develops an ontology so wide that he cannot even exemplify many cases in which it could be applied. On the one hand, this posture is positive, because it aims to leave no gaps in the presupposed ontological description. On the other hand, this posture can lead to a very exacerbated generalization.

Thus, Simons argues that a nuclear trope theory is not only possible but less costly than substrate theories. Apparently, the nuclear trope theory does not commit itself to bleak metaphysical aspects such as the problem of defining what would be a substrate, or the problem of the infinite regress. Properly, it defines that the core of an entity defines the “nature” or “essence” of that entity without considering the core as being a substrate. Such nucleus would be formed only by essential tropes. Besides it is possible to exist non-essential tropes orbiting this nucleus, acting as a “cloud” or a “shell” of tropes that are dependent on those tropes in the nucleus. In addition, he argues that there is no such thing as a free trope, all tropes exist in some kind of dependence relation. Some tropes might not depend on the others, however they would never constitute a single entity.

So, he says that each entity is based on a “foundation system” which consists of an ontological structure. Such entity has a nucleus, called by Simons as an “individual essence” or “individual nature” fulfilling the role of a substance. Since there are essential and no-essential tropes, it is therefore impossible to achieve a complete determination of any substance because always will be tropes that are necessary to define each specific kind of entity at stake.

The nucleus itself can be identified as something composed by essential tropes, whose annihilation thus implies in the annihilation of the nucleus. Other tropes related to the nucleus, but whose non presence do not imply in the annihilation of the nucleus, are the non-essential tropes. The non-essential tropes are dependent on the essential tropes (nucleus), however the nucleus does not depends on the non-essential tropes, such a dependence is said partly one-sided.

According to Simons, the main difference between his ontology and the Husserlian proposal is that the dependence is specific and not individual. This means that a nucleus can require the presence from some kind of trope (a colour), but not an individual trope (this tone of colour). While it seems a minor aspect in an ontology, it could be a very important trait in a tentative to establish a representative ontology in the quantum domain. After all, any ontology which deals with quantum entities should be highly interested in describing the kinds of entities that could act as properties of more complex entities, such as electrons and atoms.

In my opinion, at this point, Simons presents the major advantage of his theory; the flexibility of the theory, which encompasses nucleus of any sizes and complexities. According to him, it is even possible to exist a nucleus without non-essential tropes, the entities constituted in that way could be the most basic entities in the universe (SIMONS, 1994, p. 18). The tropes of this nucleus are conceived by him as non-relational properties. A natural question is: What relates this non-relational tropes? Simons does not give many hints in order to make clear this kind of structural issue. Actually, in approximately one page he put forward (superficially) several structural considerations about his ontology.

3.4.1.3 Stretching an ontology

First and foremost, Simons's ontology is flexible, since it contains several ramifications that aims to describe many kinds of entities in different domains. However, he does not offer many examples in order to makes sense to his proposal. Furthermore, the main view that any entity is composed by tropes divided into essential and non-essential tropes is a rushed point of view. Things are not that simple and we cannot simply consider that all entities and relations can be easily reduced to a single schema. Simons knows that and provides different clarifications on that matter.

The first kind of entities that he seeks to describe are the most basic ones. Without making use of examples, Simons suggests that there could exist entities composed just by their nucleus. These entities might have no clouds of tropes gravitating around them.

In addition, he suggests the existence of entities formed by several nucleus, all of them with no presence of a cloud of tropes. And, in contrast, there might be collections of tropes without a nucleus, whose entities composed by them would be the result of some kind of variation over some specific trope. Furthermore, this specific trope could be replaced by another one that could act as the new catalyst of that entity. It does not means that this trope is some kind of a free trope, but only that the tropes composing its cloud can be all replaced by others.

Besides, there could exist entities with clouds, but instead of clouds composed by dispersed tropes such clouds would be composed by clumps acting as subnucleus of essential tropes present in those entities. These clumps may require the existence of a nucleus for each clump in order to create a bridge among them, stating a necessary dependence between them. It is an interesting ontological view, however Simons does not provide an explanation for how this occurs.

There is still the possibility to find some entity with no nucleus at all, but only with a cloud of tropes acting as a substantial aggregate of tropes. For instance, water could be a good example of such an entity. However, this assumption can be easily changed if we choose a different domain of analysis.

Finally, Simons suggests the existence of relational tropes between two entities. The existence of these relational tropes would require the existence of two or more nuclei. This aspect is very interesting, however Simons does not clarify how this relational tropes are structured and directly linked with the nucleus.

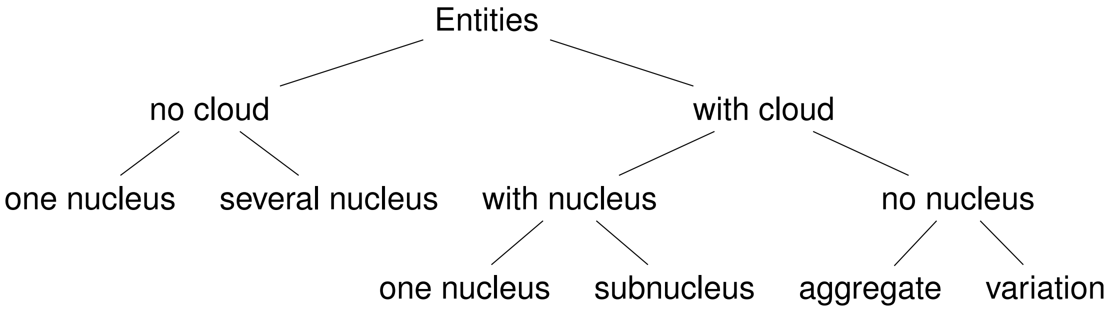

Table 7 – Simons's framework

In the end, all these options can be considered just one possible unfolding for such an ontology. Like Simons have said, "the nuclear theory shares with the bundle theory the merit of openness and flexibility" (SIMONS, 1994, p. 19), allowing one to investigate more possible relations among the categories.

3.4.1.4 Application: souping indiscernibility

Having put forward a thorough description on the several uses for the nuclear trope ontology, Simons presents only[11] one application of his ontology, which is directed towards the quantum domain.

Simons focus on the problem of indistinguishability between indiscernible quantum entities that could be in a superposition. For him this is a situation in which his on-

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[11] Simons is clear in saying that his investigation is more allusive to a new ontological approach than a complete system of ontology. Clearly, this limitation does not consist in criticism against him because, as he himself punctuates, those limitations steam from the complexity of that domain. Additionally, at the end of his paper Simons presents another great problem, the problem concerning the adequate ontological description of the probability amplitude in QM. According to him, this is hard to be examined and, at that time, he had no clue how he could set a good description for that case.

tology can be very useful. In Simons's view, his approach is better them those proposed by the substantialist and the universalist. According to him, the substance ontology does not accept that two entities can have the same properties and, in doing so, be distinct individuals, breaking away the Leibniz's Principle. In turn, the universalist can deal with the problem, however, he needs to resort to a third realm of universals, which is, as we know, a fast way to fall into the infinite regress. In turn, the nuclear trope theory is better than its opponents because it does not deal only with the entities from the quantum domain, but, also, it describes the characteristic quantum phenomena that emerge from the relations between those entities. Therefore, such entities and relations are described without making use of property instantiation.

By taking the problem of indiscernibility we can easily see how the trope theory has a flexibility that is not shared by other ontological frameworks. We have already presented several criticisms against the substantialism in the quantum domain. By seeking for sharp and well determined entities the substantialist tries to fit the quantum phenomena into an ontology that presupposes a classic behavior from its inhabitants, leading them against some serious constraints, such as the indistinguishability in QM. The superposition problem is one of those phenomena and Simons shows us how his trope theory can deal with such a case. As we know, the superposition[12], for instance, between two or more (many-system) electrons is a major problem for the substantialist because he cannot offer a definitive answer in order to describe which electron is which one[13] For the substantialist those entities still have something that confers individuality to them, however, his description does not go beyond the postulation of a mysterious substance. The substantialist cannot either say whether the electrons after a measurement are the same from before the experiment.

On other hand, in nuclear trope theory the situation is conceived in another way. According to Simons, before the measurement each electron has its own set of tropes, which can be divided into essential tropes and non-essential tropes (relational properties), such tropes are what gives rise to those entities. Each electron would be composed by two trope-bundle. One trope-bundle would be a tight bundle of essential tropes as rest mass, charge and spin forming a kernel, which would act as a substance. The other trope-bundle would be formed by non-essential tropes as position, momentum, spin-direction[14], and so on. Thus, Simons answers the question about the superposition challenge by saying that before the measurement we have two electrons, but during the superposition those electrons would be souped into a unique pseudo-substance. Hence, when we say that in a superposition between two electrons we

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[12] See Appendix B, Section B.0.1.3.

[13] See Chapter 2, Section 2.2.

[14] In addition to what we have already presented in the last section, we need to say that Simons presents some other views on how we could use trope theory to make ontological descriptions. One of these uses is the reference to a second-order trope spin-direction, which would be a kind of trope strictly linked with the first-order essential trope of spin.

have the double-mass, double-charge, double-spin, we are just saying that theirs tropes were dissolved in the superposition to give rise to a third thing with its own substance[15]. With this assumption, Simons proposes that after the measurement the electrons are recomposed by the tropes that were souped during the superposition.

> But suppose we consider the nuclear double bundle of tropes making up the nature of an electron: its essential ones, making up the kernel, and its accidental ones. When an electron is physically isolated from others, it is a substance. When two electrons with opposite spin are superposed, e.g. in a helium atom, the electrons cease to be substances, but their tropes retain their identity, and are modified by their proximity. (SIMONS, 1994, p. 22)

In line with this movement, Simons can explain how those electrons collapse and reappear from those tropes without making reference to the substances that could individualize the electrons before the superposition. Moreover, this approach allows him to say that there is no problem whether those electrons are the same from before or not, or even which one is which. What is fully consistent with QM.

After all, even with his well elaborated ontology, Simons does not make clear how a bunch of disperse tropes gives rise to a well defined entity. For me, the issue is established around the problem of foundation as it was presented above in Husserl's case. As we have seen, the problem of foundation is essential to deal with the problem of infinite regress, but to solve this problem we need to make the regress stop at some point. This is the grounding problem, that is to say, the problem of providing a stable soil to an entity to exist without appealing to another entity or ontological category. This is not a new problem and, in my view, this can be solved in Simons's case in an analogous way as that of phenomenology. In the *Logical Investigations* Husserl has the unity of consciousness as his ultimate ground; the primitive foundation towards all his ontological investigation is directed. So, in the same direction, Simons is dealing with the same necessity. He needs a background serving as a structural basis for his ontology. For Husserl all possible entities are grounded in the horizon of intentionality and directly linked with the consciousness. This is a comfortable solution because Husserl, in some extent, submitted all domains of investigation, including all regional ontologies, to consciousness. We cannot say how much Simons is interested in this kind of background, but it is possible to deduce that Simons is not interested in following Husserl's path of intentionality. Nevertheless, the main problem for Simons here is that he wants a trope ontology in order to describe any entity at any domain without appealing to a unique and cohesive framework.

Straightforwardly, the ontology by itself is not enough. On other hand, I am not saying that his strategy is wrong but, perhaps, insufficient. For me the exigence of

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[15] For me, whether substances are well represented or simulated in Simons's example is just a matter of dispute, the important is his sound handling of the indistinguishability issue.

some structural background is blatant and I believe that the best option is to assume that there is no unique ontological framework acting as a common background for all possible ontologies. Thus, in the case of the quantum domain the best option would be to delimit the domain and investigate just the formal features linked to that domain. In Simons's case, the ontological investigation over QM should be entirely dependent on their underlying formalism and axioms, all of them extracted from the physical theory itself. However, in 1994, Simons was more interested in delineating an ontology *lato sensu* instead of an ontology focalized on a specific domain. Just in 2002 (SIMONS, 2002) that this aspects become an issue for him. We will give more attention for this last approach in the next section.

3.4.2 Simons: Factored Ontologies

In a paper published in 2002 Simons (SIMONS, 2002) returns to the ontological debate in the quantum domain, but this time he is working directly over this domain and, apparently, had left the tentative to use just one ontological approach to deal with different ontological domains. His new proposal (SIMONS, 2002) is to make a review of different ontological approaches to QFT by making no reference to some specific formulation. As a result he comes to some interesting conclusions.

First, the quantum domain cannot be examined in a serious way without an extensive study of its formal aspects, which implies an unavoidable connection between ontology and the mathematical counterpart of the theory. His position is that the ontology must reflect invariant aspects of the theory. Thus, an ontology is about features that are invariant for all entities presupposed by some specific scientific inquiry. So, the mathematical invariances that represent the qualitative aspects of those entities must be preserved in the ontology.

Second, the trope category is discarded as an option that could describe *all* the quantum phenomena that arise from some specific quantum theory, however it remains as a useful category that can be used to explain many quantum phenomena. Therefore, his main criticism against trope theory is that any trope presupposes always some kind of relation of dependence, what goes against the apparently supposition that at least something must be independent at some point (FRENCH; KRAUSE, 2006, p. 365-366). Otherwise, we may fall again in the infinite regress.

Third, because of the various and unique phenomena that occur in the quantum domain, it seems almost impossible to describe those phenomena with traditional categories, which are most of the time chose to deal with some specific problem.

For us, the three points highlighted by Simons are really important and reveal how Simons position has changed over the years in order to conciliate ontology and the domain of investigation.

3.4.3 Critical remarks

First of all, I must say that both Simons's proposals have each one its merits. The first (SIMONS, 1994) provides a well described and structured approach on tropes, dealing with internal issues about the universalist approach by choosing a clear and well-defined example. The second (SIMONS, 2002) focuses on the structural features of the ontology and the physical theories.

As we can see, Simons places us fighting on two fronts, one with traditional metaphysics and the other with the contemporary metaphysics that is now erected under the auspices of the contemporary science. In this sense, Simons's proposal, in our view, has two great virtues but some vices and dangers.

Clearly, Simons's proposal clashes against the concept of substratum as a foundational and individualizing criterion for each and every entity, at least, in its original sense. Another positive aspect of his reading is the search for an ontology focused on the contemporary debate on ontology of physics.

On the other hand, in certain extent, Simons's proposal is misconceived because it consists in an attempt to preserve a connection with the traditional metaphysics by simulating the substratum category. After all, he is forced to remain within certain boundaries that already existed for the traditional metaphysics advocating the theory of substratum.

For us, Simons (SIMONS, 1994) is committed with a project way too ambitious and has several points of contact with Campbell's view about the scope of the trope ontology. We are not interested in discussing the merits of a so overarching ontology but, as we criticize in Chapter 2, a too broad ontology ranging over different domains of reality is, at least, equivocate in the scientific domain.

Finally, the main problem in Simons's proposal is identified by he himself. Properly, there is a oustanding difficulty to establish and describe the general aspects that allows the nucleus to aggregate the cloud of tropes or, as one might put, make clear what is the gravitational center of this ontological structure. As far is we concerned, he does not complete this crucial task. As we showed, the mereological approach suggested by Husserl could be easily related with a clear phenomenological background in which the consciousness act as glue for the intentional acts and its correlates. For Simons, it is difficult to establish an ontological structure able to explain all his proposal. As we will see, Kuhlmann has the same problem, he follows Simons view, however he does not present a clear link between his ontology and the formalism. This relation is the main problem for all ontologies working on the domain of physics.

3.5 KUHLMANN

In his book, *The ultimate constituents of the material world: in search of an ontology for fundamental physics*, Meinard Kuhlmann presents a new ontological approach to QFT. More precisely, his approach has an intended formulation of QFT, i.e., the *algebraic quantum field theory*[16]. Such an approach, so-called "dispositional trope ontology" consists in the development of an ontology based directly on the AQFT formalism. In this formalism fields and particles are no longer the most fundamental entities to be investigated in QFT[17]. However, despite being a sound approach, Kuhlmann's proposal find many constraints. In this sense, before we engage in the analysis, it is necessary to understand what Kuhlmann conceives by a trope ontology in general. This is an important procedure because several problems arises in his characterization of an ontology based on tropes.

3.5.1 Choosing a domain: Algebraic Quantum Field Theory

AQFT is an axiomatic approach to QFT, but, differently from QFT, it does not enjoy of the same empirical success[18]. The main idea underlying AQFT is the structure of a net of operator algebras. Such algebras are at the heart of the formalism, being considered the most basic entities in the theory, since they encode (potentially) all the physical "content of the theory"(HAAG; KASTLER, 1964, p. 848). In AQFT the empirical content of the theory is "just" coordenatizated by fields acting in finite spacetime regions (open sets in Minkowski space). Fields and particles are no longer the basic entities in the theory.

Different from other ontologies for QFT, an ontology that aims to describe quantum entities in AQFT has a great advantage compared to others. Above all, since AQFT is an axiomatized theory, an ontology for this theory disposes of a clear view of the mathematical structures at stake. In this sense, Kuhlmann's ontology has a wide lead over other possible ontologies, not only by choosing a specific formulation, but also by building a new ontological framework for that purpose. This way, he seeks to describe not just quantum entities, but, also, the structural relations that act as a condition for theirs existence (or representation). In order to describe those entities Kuhlmann proposes his dispositional trope theory.

First of all, let us now see what Kuhlmann understand by tropes. Obviously, it is not an easy task to allocate Kuhlmann's theory in some particular trope theory; his view is new and presents more constraints than progress. Despite having written three chapters on the subject by referring primarily to Williams (WILLIAMS, 1953) and

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[16] See Appendix C, Section C.2.1.2.

[17] See (KUHLMANN, 2010, p. 43).

[18] See (KUHLMANN, 2010, p. 56).

Campbell[19], he make no further remarks about the trope theory in general. Although he does not posit himself as a follower of some particular formulation of the trope theory, he says that his major inspiration comes from Simons's trope theory. According to him, the difference is that the former uses the trope theory in the context of QM, while he himself uses it in the context of QFT[20].

In my opinion, Kuhlmann's proposal has many advantages over other trope ontologies, one of them is his focus on just one approach of the quantum domain, such a strategy promotes some kind of an ontology *in vitro*. In addition, the use of AQFT is fully in line with the grounding requirement [21] because AQFT does not deny fields or particles, but interprets those entities in a different ontological level based on the net of operator algebras. Consequently, Kuhlmann pays close attention to the mathematical structures by seeking for "(...) an ontology where correspondences can be established between fundamental quantities and structural features of the scientific theory on the one side and basic entities of the ontological theory on the other side" (KUHLMANN, 2010, p. 170). This view is closely connected with the assumption that some ontological categories are much better related with the spacetime structures that underlies the scientific theories than others. By that, we can easily see why Kuhlmann prefers categories that cannot be conceived without the reference to space and time, such as tropes. As a result, Kuhlmann develops his own ontology by postulating a new type of trope, the dispositional one. Properly, his notion about what is a trope is not much different from the other ontologists, even the ontological unfolding suggested by Simons is not used by him. However, instead of his thin characterization of a trope theory, Kuhlmann lists four basic reasons for assuming an ontology of tropes as a viable and useful ontology[22].

(i) The gap between universalists and nominalists might be fulfilled with a trope theory, which is a moderate form of ontology for both universalists and nominalists;

(ii) A trope ontology can deal in a diplomatic sense with several conceptual problems that overlap universalists and nominalists;

(iii) Trope ontology is an effective theory which can explain how concrete particulars are composed by using a more fundamental category than thing or state of affairs;

(iv) It is a very economical ontology, since it fits in several ontological structures and can explain how a lot of domains can constitute theirs entities.

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[19] See (KUHLMANN, 2010, p. 143).

[20] See (KUHLMANN, 2010, p. 158).

[21] See Section 3.3.1 in the current chapter.

[22] See (KUHLMANN, 2010, p. 158).

In addition, Kuhlmann does not choose the trope category without regarding to the other categories. Thus, the presentation of the dispositional trope theory is preceded in Kuhlmann's work by the analysis of some ontological approaches on events and processes. Kuhlmann's justification for addressing attention to trope theories just in the last part of his exposition is that the trope approach is more economic and innovative than others. For now let us just assume that his option for tropes is sound. Anyway, Kuhlmann does not develop a trope theory in the context of QFT only to offer a new ontological view of this domain; as he says himself, it is about using the dispositional tropes to describe the "(...) most basic entities out of which everything is composed." (KUHLMANN, 2010, p. 196). As we shall soon see, Kuhlmann's proposal is too much ambitious and falls far short of what he is proposing.

3.5.2 Dispositional tropes

So, what are dispositional[23] tropes? Properly, dispositional tropes are tropes that "model" the (possible infinite) degrees of freedom that a physical system may have, thus this approach can "(...) be understood as comprising an infinite number of dispositional tropes." (KUHLMANN, 2010, p. 169). The main motivation for a dispositional approach in AQFT is the probabilistic feature. Such feature is intended to be represented by dispositional tropes that should represent what are the possible (probabilistic) outcomes involved at the moment of a measurement. Note that it is not an ontology about the entities themselves, but about the formal conditions encoding all the information about them. Anyway, Kuhlmann's procedure is dubious on this regard. While he takes a firm stand about what kind of probability is at stake in AQFT (the objective one), we cannot understand why he pays almost no attention to the unfolding of this key component in his ontology. In the next section we are going to pay close attention to this issue, but, for now, let us consider the novelty behind this category.

Simply put, Kuhlmann's ontology is a nuclear bundle trope theory similar to Simons's in which the non-essential tropes are reinterpreted as dispositional ones. Such dispositional feature can be set in different formulations of QFT. On one hand, Kuhlmann's opinion is that such a trope theory is apparently able to model the possible properties (or values) of some given quantum entity represented by a specific physical system before the measurement (KUHLMANN, 2010, p. 168-169). On the other hand, AQFT holds specific mathematical structures encoding the possible values for the physical system in question, which does not entail in the actual existence (or representation) of the quantum entities understood as quantum fields or particles, but just its possibility of existence.

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[23] About the uses of the concept of disposition and correlates in the context of the quantum domain see (DE RONDE, 2017).

> The structure of AQFT and (the standard one-category version of) trope ontology closely resemble each other. Both theories deviate from traditional theories, namely QFT/substance ontology, by decisively putting algebras of observables/properties at the bottom. "Traditional" entities like particles and fields/substances and universals are seem as derivable or analyzable in terms of those basic entities, i. e. observable algebras/properties. The claim that observables algebras/properties are basic and not the usual entities in traditional accounts is bold and needs to be supported by convincing reconstructions of those traditionally acknowledged entities. Again, both in AQFT and in trope ontology much effort has gone into showing how (particles and fields)/(substances and universals) can be accounted for in terms of observable algebras/properties. (KUHLMANN, 2010, p. 170).

Taking into account his particular aim, the dispositional tropes are formulated by him as non-essential tropes whose values are known just in a probabilistic sense. Because of that, he describes, for instance, an entity such as a "2-electron system" through the following equation[24]:

$$[e - tropes \mid n - tropes]_{'2el.-syst.'}$$

$$= [m = 2m_e,\ e = -2,\ s = 1 \mid prob(pos.),\ prob(spin),\ .\ , ...]$$

Clearly, the left part of the equation stands for essential[25] tropes such as the rest mass, charge and spin, while the right part stands for possible values for different observables such as position and spin direction at the moment of the measurement[26]. Needless to say that, with specificity, these observables are present in almost all quantum theories. Consequently, the concept of dispositions dovetails very well with the probabilistic features of both QM and QFT.

To summarize, dispositional tropes are closely related with the probabilistic aspect from the quantum domain, however, the AQFT is not concerned with the entities but just with the nets of algebras that encodes the information about those entities.

3.5.2.1 Probability

Again we could ask about what kind of probability is at stake here because, ultimately, the probabilistic aspect is at the heart of any theory in the quantum domain. And, by contradicting the general trend, Kuhlmann argues that he "understand quantum probabilities as objective probabilistic dispositions of quantum objects to display certain

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[24] See (KUHLMANN, 2010, p. 168).

[25] See (DALLA CHIARA; DI FRANCIA, 1993, p. 269).

[26] Remember that Simons has already punctuated that the measurement problem ought to be at the core of any ontology on the quantum domain. "[I]t is unclear to me at the present what the superposition of probability amplitudes means in ontological terms. Is a particular exact momentum a trope of an electron, or is exact momentum a theoretical construct we bring to bear on much more ethereal tropes, namely probability amplitudes to have momenta? Trope theory to date does not help us to decide more work needs to be done"(SIMONS, 1994, p. 24).

outcomes in the event of a measurement."(KUHLMANN, 2010, p. 167). Obviously, this is an astonishing assertion because most part of physicists and philosophers avoid giving a definitive answer about what is the type of probability they are applying in a given theory. Naturally, the next question should be: what kind of objective probability is at stake here? Because, as we know, probability is divided, at least, between objective probability and subjective probability[27]. After all, Kuhlmann does not provide any answer in this direction, and the ontological characterization of dispositional tropes remains unclear.

As a result, we could say that this ontology is an aprioristic one, since there is no attempt to describe the entities, but just the structural conditions that are invariant for any entity in the domain. In this sense, from a methodological point of view, our position is very alike to Kuhlmann's view on this regard. He disregards the debate between universalists and nominalists by assuming an instrumentalist attitude towards the trope ontology. Obviously, since the AQFT is not a physical theory *per se*, his instrumentalist approach cannot be confused with a pragmatic one. Basically, in his ontology we are looking directly towards the ontological framework attached to the theory and never to some isolate phenomena, or even towards the observables that are encoded by the formalism. In this sense, any critics against Kuhlmann's lack of an adequate "(...) link between his dispositional tropes and the experimental practice" (ROSSANESE, 2013, p. 419) are not in line with the idea behind the connection between AQFT and dispositions. Of course, we are not saying that the discussion on that matter is pointless, however, the AQFT approach works on the foundational and structural levels for different quantum field theories focusing on the encoded information by means of the nets of algebras and not in the "(...) coordenatization of this net of algebras." (HAAG, 2012, p. 106) Again, the AQFT is dealing with the conditions and not with the resulting of the quantum field theories.

3.5.3 Ontology without entities

Aside from the fact that tropes are conceived as dispositions, Kuhlmann's view is very similar with Simons's proposal. However, we cannot let this proximity makes us believe that it is possible to reduce one ontology to the other only based on the change in the trope category definition. This misconception is a risk if we consider only the category itself and not the formal background that stands for the ontological structures in Kuhlmann's theory.

Remember that Simons is seeking for a trope theory able to deal with entities in contexts other than the quantum domain. Actually, the example of the indistinguishability case in QM serves just as an example of application of his ontology in a specific domain. Given the extent of his approach, he loses the specificity that an ontological investigation

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[27] See (DA COSTA, 1993, p. 57).

in the quantum domain requires. For instance, whether one considers Simons's view on the quantum domain, it becomes easier to see that his proposal puts the entities in the foreground and the theory in the background. This methodological option makes his ontology an ontology oriented by the entities and not by the structural aspects of the domain of investigation.

On its turn, Kuhlmann's theory can be conceived in a double sense. First, in a very similar sense, the entities can be understood as fundamental in the ontology, and the dispositional feature would be just an improvement over Simons's theory. However, albeit Kuhlmann chooses the AQFT as his background, he does not investigate the structural features underlying his ontological approach. The final outcome is a reversion of the ontological requirement for the entities. Let us see how Simons's and Kuhlmann's views diverge on this regard. In a simplistic way we could chart the aforementioned ontological assumptions as follows: Here we see how Simons approach goes for the grounding problem. Basically, he takes first the quantum entity at the down level then to open it in its possible categories.

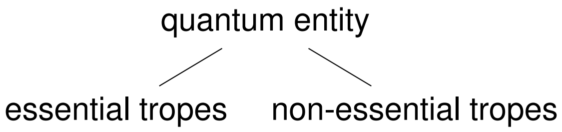

Table 8 – Simons's basic framework

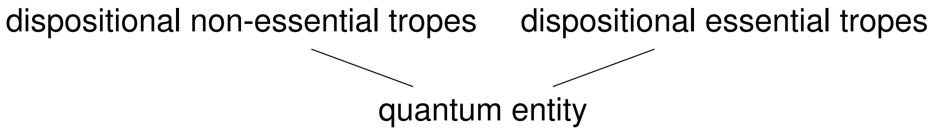

Table 9 – Kuhlmann's basic framework

Kuhlmann, on other hand, takes the entity as result of the structural framework of the theory and places the entity after the stage of the categorial analysis.

Since the two first schemes are almost the same, it becomes easy to see that the difference between them is that the former opts for a bottom down ontology, whereas the latter chooses a bottom up ontology. Kuhlmann inverts the ontological structure by pushing the entities to a secondary role in the ontological description. Notice that both presuppose the existence of the entities, however, while the former is just a description about the entities, the latter makes the presupposition of existence but suspends any description about the non-essential tropes until the measurement. As we can see, the picture is entirely changed when the formal background is specified. In the case of

Kuhlmann's proposal the situation is more emblematic because the AQFT displaces the traditional concept of a quantum field to a secondary level.

After all that, the main question remains: How (dispositional) tropes are linked with nets of operator algebras? The first answer is that Kuhlmann does not provide the answer. The second answer is that he describes the main insight behind his position, which is described below.

For Kuhlmann there is a clear motivation to link dispositional tropes with representations of operator algebras. As we have advanced before, the algebras are the C^*-algebras, however, in AQFT one is interested with the concrete representation of this algebras as bounded operator $\mathcal{B}$ in a Hilbert space, $(\mathcal{B})\mathcal{H}$. The attribution of such algebras to open regions in the Minkowski space encodes the possibilities around the possible entities in the theory. This is why one says that this structure encodes the theory, while the fields coordenatize the physical content of the theory. Thus, the problem is not present at the theory itself or in the trope theory but in the linkage between these two approaches.

> Regarding the distinction between essential and non essential tropes one possibility is to say that the net $\mathcal{O} \to \mathcal{A}(\mathcal{O}), \mathcal{O}\mathcal{B} \in (M^{28})$ encodes the essential "tropes" and the state the non-essential ones. Note that tropes comprise properties and relations, as long as they are thought of as particulars. Therefore it is no problem to have, e.g., the relation of the mappings $\mathcal{O}_1 \to \mathcal{A}(\mathcal{O}_1)$ and $\mathcal{O}_2 \to \mathcal{A}(\mathcal{O}_2)$ or of $\mathcal{O}_3 \to \mathcal{A}(\mathcal{O}_3)$ and $\mathcal{O}_4 \to \mathcal{A}(\mathcal{O}_4)$ among the tropes in this approach of a trope-ontological understanding of AQFT. Although I think that this line of thought is not wrong, but it is unsatisfactory for my taste. It puts all the burden of detail and explicitness on the shoulders of the physicist. I would like to see if it is possible to get at least one step further in order to reach a stage where a more explicit identification of entities or structures in AQFT with tropes can be given.(KUHLMANN, 2010, p. 174-175)

Following the quotation it becomes clear that there is a strong insight on Kuhlmann's proposal. In fact, the net of operator algebras encodes the structural information towards the regions $\mathcal{O}_i$ in the base space M. On other hand, Kuhlmann does not provide any formal link and neither a precise definition of the trope category that could help us to connect one insight with the other after all.

3.5.4 Critical remarks

Whether we look at the reasons why Kuhlmann chooses tropes as a good ontological option, we can notice that his reasons do not reflect the needs of an ontology of physics, but just the needs of an ontology in general. His methodological position does not consider the domain itself but consists only in comparing his trope theory with other possible candidates.

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[28] "M" states for Minkowski space.

In addition to other problems, the most problematic aspect of Kuhlmann's trope theory is an apparent circularity in the definition of the trope category. Briefly, the trope category is usually defined, and informally too, as an abstract particular that is spatiotemporally defined. As we can easily see, quantum entities differ significantly from everyday entities which are well determined, having no problem with localization even in the classical domain of physics. But the image differs quite dramatically in the quantum domain, where an entity never has its position and momentum determined with absolute (infinite) precision (FALKENBURG, 2007, p. 221).

One aspect that Kuhlmann's ontology lacks is a clear definition of the concept of disposition. Generally, understood as second-order properties, dispositions generally require a first-order property or category[29]. Would that be the case of dispositional tropes? Kuhlmann does not provide further considerations on this point after all.

Thus, we see that by the usual trope definition that this category presupposes (since it was generated for this purpose) to deal with macroscopic entities or punctual ones when represented in CM. This definition also arises because the abstract character of the category implies that it has no extension at all, avoiding that tropes might be understood in the same sense as a particular concrete (reism). On the other hand, the spatiotemporal characterization also avoids the universalist view about those entities.

At this point, we could say that Kuhlmann has taken the best methodological option. But, while it is true, he fails in two main points. First, he is not able to show, by using the theory, how dispositional tropes and AQFT are linked[30]. Second, Kuhlmann does not go much beyond Simons in making an effective approach towards other quantum phenomena. Mainly, the probabilistic feature of the theory, essential for the own definition of the cncept of disposition, is left aside without major considerations.

3.6 FINAL REMARKS

Or the approaches investigated here were only able to deal only with one kind of phenomena in a theory (Simons/superposition/QM), or, when they proposed specific ontologies over some specific domain in a relatively global way (Kuhlmann/AQFT), they opted for ontological categories that in the end cannot deal with central aspects of the theories. Not to mention, that different quantum theories can have different principles and theorems, making the domain a conceptual minefield for any ontological investigation.

Simons suggests, via nuclear trope theory, a very interesting solution to the problem of superposition, but it does not include, as Simons himself says, a solution for the problem of measurement, which is closely related with the former. In 2002, Simons seems to abandon the theory of tropes, mainly because in a mereological

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[29] See (LOWE, 2006, p. 121).

[30] This criticism was already made by Rossanese. See (ROSSANESE, 2013).

perspective around the dependence relation between tropes they appears just as parts of a whole (entity); such a whole has no support and neither an ontological status *per se*. Moreover, since tropes are in a dependence relation, it is justified to require something independent in the relation, however it is not the case in trope theory. For me, this abandon is a step back because it is not the result of some kind of mismatch between tropes and physical theories. Actually, it is a decision based on an attempt to restate the substance paradigm by introducing an independent (substratum) in the theory. In turn, Kuhlmann reformulates the proposal of Simons and starts to offer an ontology of dispositional tropes that is unable to describe more than some set of specific features of a physical system.

For this reason, the major treat for the tropist in the quantum domain is not the universalist or the radical nominalism, but the ontological challenges presented by the domain itself. As we could see, tropes are defined as describing any entity as individualized in space and time. However, when we go to the quantum domain and throw the problem of the indiscernibles[31] into the ontology of tropes, it is unable to explain what is an indiscernible, or quite the contrary, it comes to be considered a merit that the ontology of tropes implies in the individuation of indiscernibles through weak indiscernibility. Tropes ground their discernibility on space and time, however, in the quantum domain the indisceribility between entities of the same type is a fact. Hitherto, it is still an unsolved problem for the tropist, and Kuhlmann does not represent an exception in this case.

Notice how this negative result is not based on a matter of preference and not even on the problem of indiscernibility as we could deduce from the beginning, but it is totally based on the problem of measurement and the uncertainty principle. Our criticism is not against the explanatory power of the trope category, but against its definition, which contradicts the most sensitive principles of the quantum domain.

For instance, in QM two complementary observables cannot be measured simultaneously, being position and moment two emblematic cases of this process. Moreover, the problem goes even further, even if we wanted to obtain only the position of a particle, the trope position is never defined with exact precision (infinite precision). The position of a quantum entity, such as an electron, can only be obtained by a probabilistic approximation, which seems to have an ontological aspect and not a epistemological one. The impossibility of knowing where the electron is with precision is due to a feature of the theory. Here we come to our point. If a quantum entity like the electron (which is understood to have no dimension) can never have its position accurately obtained (perhaps because it does not have any) how can we attempt to describe the ontological characteristics of this entity by means of tropes that are always well-defined in space and time? At the moment this questions seems not bother anyone interested for tropes.

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[31] See (FRENCH; KRAUSE, 2006, Chapter 1).

After all, if we think of observables (mass, position, spin, etc.) as tropes of quantum entities, then these entities must be spatiotemporally well defined, but this does not occur in QM. The problem is that the trope definition presupposes a classic view of the entities with respect to their temporal and spatial disposition, whereas in the quantum domain the maximum we can get is the probability that these tropes might be given in an entity in a certain region.

As a result, the descriptive inability of trope theory leads to a circularity of the trope definition, and aspects that were trivial aspects in the everyday dealing becomes a serious problem for the tropist in the quantum domain.

4 EVENTS AND PROCESSES

> *"Ontology does not come free;*
> *it demands concepts for representation."*
> Auyang, 2002, p. 118.

4.1 INTRODUCTION

In our crusade for the most suitable categories for the description of the physical theories we were pushed towards the idea that such categories must be something not only spatiotemporalized, such as tropes, but, in some extent, dynamical (FALKENBURG, 2007, p. 228). That is why the categories of event and process become important at this point. Seemingly, both categories evoke the same dynamical features present in the quantum domain. Event category[1] is used to describe reality in terms of something that happens at some region of space during some time interval. Simple examples of that are a basketball match or the Battle of Trafalgar, or even sitting in a bench during lunch. For us, the idea is very interesting because we could apparently describe several physical phenomena by using such a category. Process category, just like events, includes dynamical aspects in its descriptions, however, unlike events, processes are always disposed in time as *occurents*. For example, while events can be viewed as a whole contained in a region of space and time such as the Battle of Trafalgar, processes are ongoing situations extended in space and time as the fighting feature of the Battle of Trafalgar. Thus, processes seize situations that are occurring, whereas events are concentrated wholes in regions of space and time. Perhaps, the dynamical traits of the quantum domain might have found their ontological representatives. Could we describe the entities of the quantum domain and the relations among them by means of events or processes?

For some philosophers of science it seems to be the case. The exigence for more dynamical categories occurs because in QFT the entities (excitations in a quantum field) have dynamical features that cannot be encapsulated by some particularist view, even when they appears to preserve some sort of substantialism. From that, particularized categories like things, state of affairs, facts and others find many obstacles to model those dynamical features. On other hand, events and processes are powerful ontological tools to describe situations that do not require sharp spatiotemporal boundaries for the entities.

In the following pages I will examine both categories by comparing them with the previous options that we have already studied. Our main focus will be on two specific approaches to QFT. In this case we analyze two different options. First, we will examine Auyang's proposal for and event ontology (AUYANG, 1995). After that we will analyze

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[1] For more details about the event category see (CASATI; VARZI, 2015).

Seibt's process ontology (SEIBT, 2002). Both approaches have various virtues. On one hand, Auyang privileges the mathematical structures into play in QFT and based on that she suggests the event category; a methodological approach overlooked by many philosophers. After choosing the specific event category she changes the usual definition of the category to make it compatible with many structural features of QFT. On the other hand, Seibt suggests first the category, and, just then, she applies it to the theory. In the end, we will see that both proposals achieve much results in their descriptions, however they still continue to privilege just one singular category each.

4.2 OVERVIEW

In Chapter 2 we discussed the problems around the substantivalist view. From there we achieved the assumption that substances cannot deal with several aspects of the quantum entities. Furthermore, the substantialist picture is closely related with the object picture which is incompatible with many aspects of quantum physics. And, as we have seen in Chapter 3, Simons's nuclear trope theory (SIMONS, 1994) configures an attempt to deal with this problem by inserting an structural approach that can be viewed as a "pseudo-substance" approach. However, even the trope theory is unable to grasp all characteristic entities living inside the the quantum domain[2]. In turn, for some philosophers, there are fundamental aspects of reality described by quantum theories that can be better described by other ontological categories than those of a substance or any structural substantialism simulating the category of a substance.

The event category is one of these categories. The event category has many virtues. One of them is that events may be an alternative path for the substantialist view. This happens because, even not being particularized as tropes, events still may deal with ostensive contexts.

Obviously, we can talk about future events as well, like the next Holiday trip or the chess match occurring in the yard as the event chess match. In turn, the process category can be viewed as a description for something occurring right now, like the reading-this-text process right now. One great advantage is that when processes are reduced to regions of space and time they may be viewed as events as well. The most attractive aspect of processes is that they seem to fit in the description of fuzzy situations, like unsharp localization or continuous (and discrete) changes through time. Apparently both categories may find a place in the ontologies for physical theories. In the case of quantum theories, it is easy to see that many phenomena or even the characterization of the entities have non-classical behaviours that could match with both categories.

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[2] See (SIMONS, 2002), (SCHNEIDER, 2006).

4.3 AUYANG

First of all, let us say that Auyang's book *How Quantum Field Theory is possible?* provides an interesting and unique view about events in the context of QFT both free and interaction pictures (AUYANG, 1995). Her approach is mostly based on the fiber bundle formulation for QFT, focusing primarily on the elements of differential geometry. Such an approach, as we will see, has two major advantages. First, it gives a "big picture" of the theory beyond the wall of calculations, however it still retains central aspects of the theory, such as the interaction field and gauge symmetries. Second, the use of fiber bundles allows one to see the most dynamical aspects of the theory by dealing with the question about what parts of the formalism must be considered in the ontological research on quantum fields. Unlike other proposals, Auyang's ontology is closely linked with the mathematical formalism of QFT. This way, our first step cannot be other than take the same path, and to present the fiber formulation for QFT as made by her.

4.3.1 Fiber Bundle formulation for QFT

Here I present the general lines of the fiber bundle formulation of QFT presented in Auyang's book[3]. Additional remarks are made, and neither all elements of this exposition are present in her presentation. Thus, the present presentation is more detailed in terms of the operators, however, it does not entail that the fiber bundle formulation conserves all the features described here.

A fiber is something intricate. In differential geometry, a n-dimensional Manifold $\mathcal{M}$ is a topological space in which for each point x in the manifold there is a neighborhood at the point that is homeomorphic (resemble) to the n-Euclidean space. As we know, for each point x in the manifold there is a tangent vector p_x to the point, and all the tangent vectors on a single point in the manifold generate a vector space tangent to that point. This tangent vector space is called a *fiber*. The disjoint union of all vector spaces that are tangent to all points in the manifold gives rise to a fiber bundle - in this case a vector bundle. An important characteristic of a vector bundle is that a fiber (tangent space) is the projection of the space over the point x in $\mathcal{M}$. For instance, when the fiber is a vector space the projection assigns a vector to the point x; here we represent the projection by π. In this case a *section* can be viewed as a projection (continuous map) that gives a vector for each point on $\mathcal{M}$. In this case, a section is a *vector field*.

Another important kind of bundle is the *principal bundle*. The principal bundle P is a bundle with a structure of group G. In this sense there is an action of group G on P, $G \times P$. To each principal bundle is attached an associated bundle. Both bundles are mutually defined by sharing the same group structure over a point in the *base*

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[3] See (AUYANG, 1995, Appendix B).

space M. For example, if the principal bundle is a frame bundle, then the associated bundle is the vector bundle; and each point x in $\mathcal{M}$ is associated with all ordered bases (a fiber of the principal bundle) for the associated fiber (tangent space) on the same point. Additionally, there are different types of fiber bundles that are related to different associated bundles.

Remember that in physics a field is a physical system with infinite degrees of freedom. This means that for a continuous parameter x in the base space (spacetime) there is a field operator $\varphi(x)$, i.e. a time-dependent operator field, that generates a section θ for each instant of time in the fiber bundle, where each θ_i is conceived as an individual possible state space of the field at the point x. Thus, $\theta(x)$ is the point in the state space which is associated with the point x for a fiber $\varphi(x)$. In some extent, like any measurement in non-relativistic QM, in QFT we can project the state $|\phi\rangle$ of the system under the eigenspace of the operator. In this instance, $\varphi(x)$ is not a function, but an *operator-valued-function* that for each point in the spacetime assigns a field. Actually, $\varphi(x)$ should be called an *operator-value-distribution*[4] because when a measure is made at one point x a disturbance on the neighborhood of that point is observed; and more accurate measurements on the point increases the disturbance. In this case, a distribution does not provide a value at the point x, but rather average values at small regions nearby the point.

The figure below show us the associated bundle D representing the matter field, while the principal bundle P represents the interaction field. In the space base M, now viewed as the spacetime, γ represents a timelike curve[5], whose partial derivative ∂_μ gives the total change along γ. The decomposition of $\hat{\partial_\mu}$ (the partial derivative of sections of γ in P) gives us:

$$\hat{\partial_\mu} = \nabla_\mu + A^*_\mu$$

> The difference between the covariant derivative ∇_μ and the partial derivative $\hat{\partial_\mu}$ is called the *fundamental vector* A^*_μ. It determines the dynamical variation of the system and is directly related to the *interaction potential* A_μ. The fundamental vector A^*_μ uniquely determines a point $\theta(x)$ in the vector bundle. $\theta(x)$ specifies the phase of the matter field. Thus the matter and interaction field is coupled at the point x. (AUYANG, 1995, p. 221)

A symmetry group G preserves the system invariant while one state is lead into another possible state. This way, the possible states are conceived as belonging to the same equivalence class ($G - orbit$) with respect to G, (BARUT; RACZKA, 1980, p. 407). Finally, when we take another point x' in γ then the changing values between x and x' will induce a nonzero curvature representing the intensity of the interaction field.

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[4] It is necessary to be careful when talking about field operators as indexed by spacetime (base space) points. See (HALVORSON; MÜGER, 2006, p. 42-43).

[5] Briefly, γ is required to be timelike to preserve micro-causality. See Appendix C.

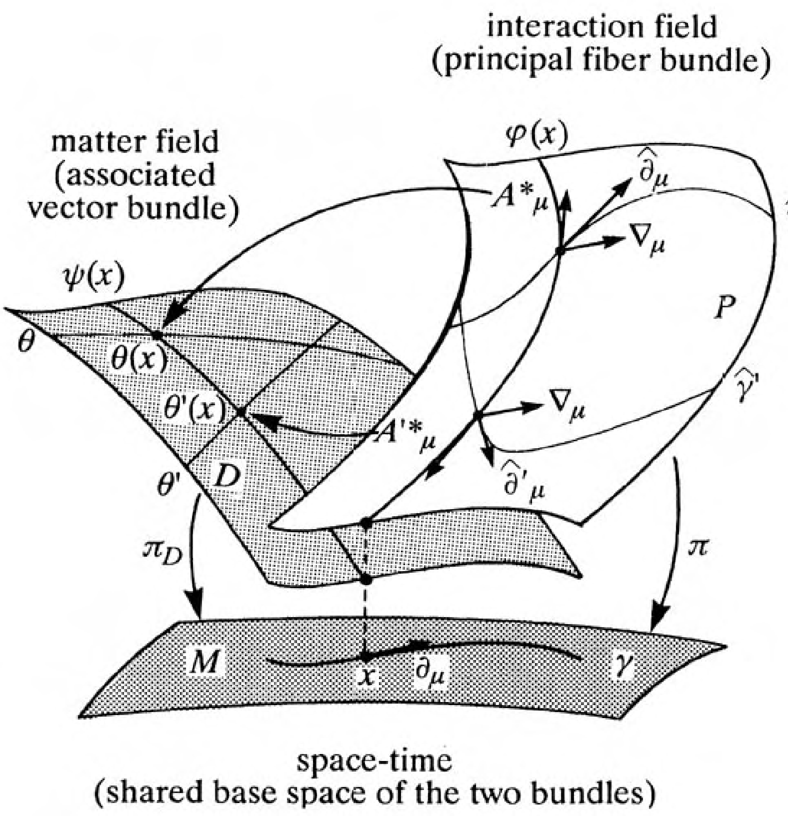

Figure 1 – Fiber bundle formulation for QFT (extracted from Auyang)

4.3.2 Events

Auyang reinterprets the traditional definition of events and give them another meaning. For her, events may contain the object idea without appealing to the thing picture by preserving the dynamical aspects of QFT. “An event is a dynamical quantity; it is the transformation of the state of the field system at a certain point” (AUYANG, 1995, p. 129). The concept of event present by her is two-folded. First, she uses the concept of a fiber $\varphi(x)$ to illustrate what is an event (AUYANG, 1995, p. 216). Second, she refers to the class of states space of $\varphi(x)$, $\theta(x)_i$, as the kinds of an entity/event (AUYANG, 1995, p. 127). Furthermore, she introduces the concept of modality since each class of state spaces involves all the possibilities around an event. “In physical theories, a kind of an entity is defined by a systematic circumscription of admissible properties; things of the same kind share the same possibilities” (AUYANG, 1995, p. 127). It is possible because the group action of the symmetry group G on the state space θ gives rise to $G - orbits$ (class equivalence) representing those kinds [6]. So, “[i]n field theories, a fiber $\varphi(x)$ is interpreted as an event or an entity in the field and a point θ in the fiber as a possible characteristic of the event.”(AUYANG, 1995, p. 216)

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[6] See (CASTELLANI, 1998, p. 184).

Following Auyang we can see that a rigorous ontological approach in QFT cannot ignore the mathematical aspects of the theory. The result is a consonance between ontological categories and physical theory. Quantum fields are dynamical distributions and cannot be compared with self-contained entities. Furthermore, this ontological aspect is really close related to the mathematical concept of a field. Additionally, the group symmetry action on the state space is related to the possible events.

After all, QFT states that elementary particles are not sharp particles at all, but just excited states of quantum fields. This is a good reason to abandon the idea that elementary particles are things to be discovered. Since quantum fields and the entities that are represented by them are fully grounded in the spacetime, any category that intends to describe those entities must be in accordance to this relation. According to Auyang, the category that accomplish this task is the event category.

Finally, we can see that Auyang adopts a different notion of event. Instead of adopting the standard assumption that an event is an occurrence in space and time, her view is closely linked with the mathematical aspects of the theory. For her "[a]n event is an entity in a interacting field".

4.3.3 Critical remarks

So far, it seems that three tasks must be accomplished in the ontological research on physical theories: i) find the mathematical structures that must be explicitly linked with the ontology; ii) find the necessary ontological tools for such undertaking; iii) make the most faithful link between theory and ontology as possible.

When Auyang proposes her ontology she decides what parts of the formalism must be considered in the ontological approach and what parts must be considered just as mathematical aspects of the theory (surplus structure[7]). Clearly, she justifies her choice by making clear references to the mathematical formalism. She finds the essential aspects of QFT and connect them with the event category, but many (essential) aspects of the mathematical formalism are left aside in this process.

This is a complicated procedure because an overly restricted approach on the mathematical aspects can lead to an excessive focus on some parts of the theory by neglecting others. Conversely, an ontology overpopulated with mathematical apparatuses may lose its specificity as an investigation about the "essential" aspects of a given theory.

Properly, Auyang's ontology is primarily linked with the final product of her ontology, namely, events. However, if we look with more attention, events and theirs mathematical counterparts (fibers and its space states) are just part of the story. There are other elements that do not receive an ontological counterpart, such as symmetry groups (local and global). Auyang extensively uses those structures to show how her

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[7] See (REDHEAD, 1975, p. 88).

event category works, however, as we know, such structures are at the core of the physical theories. If we remember Noether's theorem we can easily see how important symmetries are. It is not possible to think in conservation law and invariance without appealing to them.

In the end, Auyang's event ontology has major advantages over other approaches. For example, her use of events as ontological category does not illustrates how is possible to deal with quantum entities without recurring to substances or particularized entities. Furthermore, events, similarly to fields, are totally related with space-time, and Auyang made exactly that connection. On other hand, she does not give any major clarifications about the category itself. Her approach is turned highly based on the theory and does not provide any further definition of the category. Below, much of was said is illustrated by the following quotes.

- "An event is a dynamical quantity; it is the transformation of the state of the field system at a certain point." (AUYANG, 1995, p. 216)
- "(...) in field theories, a fiber $\phi(x)$ is interpreted as an event or an entity in the field and a point θ in the fiber as a possible characteristic of the event." (AUYANG, 1995, p. 216)
- "In physical theories, a kind of an entity is defined by a systematic circumscription of admissible properties; things of the same kind share the same possibilities." (AUYANG, 1995, p. 127)

This quotes reveal how deep is Auyang commitment with the mathematical support of her ontology. Basically, she provides us with the mathematical definition and, then, attributes an ontological status for the same definition. Sometimes it seems that her approach is based on labeling aspects of the theory instead of offering an ontological description for it.

Finally, Auyang follows the same strategy as Simons and Kuhlmann by choosing just one ontological category. After all, it seems that by taking just one category and correlate it to a specific structure impedes one of evaluating the great variety of structures still requiring an adequate ontological description. In this cases, there is just one privileged structure, or class of structures.

4.4 PROCESSES

Our last examination deals with the process category. This controversial category has gained much space in ontology in the last decades[8], and today one of its main defenders is Johanna Seibt (SEIBT, 2002). Mostly, our debate on process ontology

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[8] See (CASATI; VARZI, 2015).

will be directed towards her Axiomatic Process Theory[9]. Likely some other ontological frameworks that we have already examined, APT is a system of ontology very general and sprayed throughout many domains. Consequently, the aspects of the quantum domain are not the main ones to be considered in such an ontology. Process ontology can model several dynamical features presented by everyday entities and Seibt explores those features with close attention.

4.4.1 Overview

Properly, the better way to explain what is a process is by means of examples. In this instance, reading a book, resolving a problem, shooting electrons against a screen are examples of processes. A process is not what is happening during a time interval in a region of space, but it is the happening itself. The process category has several virtues, many of which fit very well in the description of the quantum domain. Notice that whether we want to describe, for example, the falling of a comet into the moon we can appeal to different categories to describe it. In this sense, we can refer to the possible *state of affairs* that *a comet will collide against the Aristoteles crater*, or the *fact* that *the comet fell on the Eudoxus crater*, or even the *event* that *the collision hurled debris into space*. In this specific case, the process category is trying to grasp the falling process or the hurling debris process. Clearly, we could use the event category at any instant of the process by giving it the coordinates and velocities of the comet at each moment of the falling. However, it does not result in the same ontological meaning of the falling itself.

In this regard, the process category tries to escape from the *this picture*. Properly, the this picture is grounded on the assumption that all entities can be reduced to occurrences at some region of space and time, or that they are dependent on something to exist (substance picture). Seibt's approach goes in the opposite direction by showing that is possible to make ontology without being spelled by the myth of substance. Additionally, process might be applied to the investigation of entities that are based on mathematical characterizations, like fields (SEIBT, 2002, p. 87).

4.5 SEIBT

The first aspect of Seibt's ontology that must be take into account is her criticism against the concept of substance, such criticism consists in the bases of her methodological procedure. Roughly[10], such a procedure sustains that any serious ontology must pass by a critical review of its own conceptual basis. According to her, to find or to generate a suitable ontology for QFT is an activity that requires a conceptual revision

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[9] Actually, Seibt presents different names for the same ontological framework, such as General Process Ontology and Free Process Ontology. See (SEIBT, 2009).

[10] See (SEIBT, 2009, p. 483).

with formal adequacy to the mathematical main features of the domain. The revision of the theoretical biases of an ontology is needed to trace a line separating ontology scientifically oriented from the concepts absorbed by the philosophical tradition (SEIBT, 2002, p. 54). Since we have already pointed out several criticisms against the substance picture, we will not present Seibt's criticism against the concept of substance and its derivations. Our main attention will be oriented towards her proposal of a process ontology and its possible application as an ontological framework for the quantum domain.

According to Seibt, the category type might be defined by different features like particular, individual, complex, fuzzy, and so on. (SEIBT, 2009, p. 483). For example, event category can have features like being extended in time with fuzzy spacial boundaries or can be defined as instantaneous and concrete.

Basically, Seibt has a twofolded procedure towards ontology. First, she considers that ontology must be build in an agentive way, what means that ontology relies on performative aspects of a group or activity. Second, she conceives ontology as a reductive ontology of processes, which is "[. . .] well-founded, formally simple, and monocategorial" (SEIBT, 2002, p. 87). Since our focus resides in her approach towards QFT, I shall not pay attention to the performative approach suggested by her.

Thus, for now on we are going to focus only on the process category as exposed by her (SEIBT, 2002), (SEIBT, 2009). On the whole, I do not intend to recover the full set of arguments presented by her. The aim is to give a general *aperçu* of the traditional concepts that she needs to deal with the quantum domain.

4.5.0.1 Processes

Here I follow Seibt's paper "'Quanta' Tropes, or Processes: Ontologies for QFT. Beyond the myth of substance" (2002). Properly, in the paper she uses the term "free process" to denote what she understand as a process, however, in recent papers, she uses different terms as such "general process"[11]. Seibt defines the concept of a free process from the perspective that reality does not need to be interpreted as a room full of particular entities passively waiting to be described. Actually, Seibt's crusade against the concept of substance boost her ontology towards an ontology descentered from substantialism and its immediate sibling particularism.

First, the main challenge face by her is to put aside *particularism* without loosing *invidualism*. Additionally, she needs to overcome other difficulties, such as defining a process as a well-founded category. Thus, Seibt proposes a process ontology in which there is no room for the concept of substance, neither to that of particular. In turn, she advocates that (free) processes are concrete individuals countable or uncountable. With

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[11] According to her, the term "free process" failed to signify that individual processes are non-particulars. See (SEIBT, 2009, p. 485, note 18).

this in mind, we need to understand how is possible to build up individuals that are not particulars, and how individuals can be countable or uncountable. After that, the task will be to insert such category in the description of physical theories.

First and foremost, Seibt advocates that individualization cannot be reduced to particularization. By particularization one can understand two things; an entity defined in terms of some allocation in space and time; or an entity defined in terms of a subject-predicate relation with well determined properties. Unlike this view, she sustains that individuals do not need to be reduced neither to their localization in space and time (as tropes does) nor to the dependency relation between a subject and its predicates (substantialism). She argues that the conception that individuals are individuate by some *thisness* is incorrect. Actually, both concepts individuality and particularity arise from language and not from any material entity. Such argumentation seeks to show that substantialism is a matter of language, and, consequently, ontology cannot ignore language analysis.

Apparently, we are always lead to the particularization of an entity, and so returning to the substance picture. Sentences like “The house is a shelter” inserts “house” as an individuated subject of the sentence, which is generally connected with the assumption that there is some *houseness* underliyng as a substratum of that entity. Thus, a sentence like “A coccon is the house of a larvae” illustrates how the word “house” can be removed from its role as subject to become dependent of a new subject with another substratum, the *cocooness*. The conception of substance as attached to some subject arises from language, and that is why ontology must be serious concerned with the language analysis.

This way, concrete particulars are thing-like entities defined primarily in language, so to speak, they are packed entities with well know boundaries and characterizations. On other hand, the idea with free processes is to preserve the individuality of several types of entities without resorting to particularity.

For the sake of example, a wedding is an individual countable process that is not a particular like a house or a coccon. A wedding is something that occurs during a time interval in a region of space, however, it cannot be amassed to the point to be considered an entity like a house. From here, since thisness is established over language, Seibt advocates that ontology can be structured in order to grasp the agentive aspects of language and translate them into the ontology. Consequently, since language is not reducible to its ostensive use, many other aspects of language are still to be taken into consideration by ontology.

4.5.1 Free processes

Basically, for Seibt free process are subjectless activities, and activities are concrete non-countable individuals (SEIBT, 2002, p. 83-84). After all, if free processes were subjects, then they could be predicated and automatically be particularized. For instance, a process such as the falling of an apple of a tree is about what is occurring and not about a subject and a predicate at some instant of space and time. If we reduce it to the relation subject-predicate, then it would be threatened by the risk to become another thing than a process. Above all, "(...) free process are *not particulars*" (SEIBT, 2002, p. 85), but they still are concrete individuals.

> Free processes are (i) concrete or spatio-temporally occurrent (ii) individuals that are (iii) 'dynamic stuffs' rather than changes in a subject, (iv) They are non-particulars or (contingently) multiply occurrent. (v) They are not fully determinate, i.e., they have different degrees of specificity or determinateness. (vi) Simple free processes are not directed developments (events) but are dynamically homomerous. (SEIBT, 2002, p. 86)

Since free processes cannot be in a subject-property relation, Seibt defines other kind of relation for them; a dependence relation in a mereological sense. This relation is the part-like relation know as *homomerity*. That is to say, the relation in which each part of an entity is structurally the same as the whole. Since the homomerity relation is non-transitive, Seibt's mereology is non-classical. In fact, a transitive part-relation could imply in immediate intensionality, what could lead to the unwanted result that a proper part would be the entity itself. Although structurally the same as the whole, a homomerous part cannot be the same as the homomerous entity from which it emerges.

Basically, free process are homomerous, that is to say, all its parts are still free process. For example, each part of "it is snowing" is "snowing" as well as each part of a music is still a music of the same kind (SEIBT, 2002). Furthermore, free process must not be confused with specific occurrences during a process such as, for example, the desaceleration of a bullet passing through some obstacle. Such spike situations can be viewed as events instead of processes. In particular, Grenon and Smith have suggested events as a subcategory of processes[12].

Additionally, free process are not determined by some predicative description. "They are not modelled on a single movement of a classical particle with determinate trajectory but on a dynamic conditioning of a spacetime region such as snowing or music." (SEIBT, 2002, p. 86) The movement of a particle on a single trajectory is something that particularizes the entity. If we return to Grenon and Smith's scheme again, we can remember that they have already suggested lines as SNAP entities, which is not the case of free processes[13].

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[12] See Table 6.

[13] See Table 5.

4.6 QUANTA AND PROCESSES

Seibt's main attention in the quantum domain is oriented towards QFT. Clearly, quantum entities in this case are conceptually represented by quantum fields, and Seibt is aware of the difficulties that an ontological approach would have in such a context. First, she argues against Auyang's proposal of an event ontology in QFT. For her, Auyang's interpretation of events as representing punctual interactions is just a reproduction of the particularist picture. Seibt states that "[. . .] Auyang emphasizes, in the spirit of a traditional substance ontological dualism (. . .), that basic ontological entities are definitional constructs of a qualifying and an individuating 'dimension'; the qualifying dimension consists of general entities, the individuating dimension of particulars (spacetime points)" (SEIBT, 2002, p. 81).

Based on the assumption that quantum entities in QFT cannot be ontologically described without considering the entire framework of a quantum field, Seibt tries to define the measurement process in terms of free processes.

Roughly, her explanation depends on the distinction between *amount* and *quanta*[14] of free processes. For her, amounts of stuffs, like coffee in a cup, can be defined as a particular since it exists only at that cup in a given localization and in a given interval of time (*this* amount of coffee). In this sense, amounts are the only type of a particular in her ontology (SEIBT, 2002, p. 88). Additionally, amounts are countable. For example, the coffe in the cup can be countable as the first cup of coffee of the day, whose ordinal-countability is defined in space and time localization. Following this, Seibt introduces a distinction between an amount of a process and a quantum of a process. By a quantum of a process she means the measuring units of a measurable property contained in the amount. In the case of a cup of coffee, the properties related to the amount of coffee can be, for instance, volume, temperature, and so on. For example, the quanta of the volume of coffee can be viewed as a measurable unit d of $200d$, however if we divide the quanta into two quanta unit d_j and d_k, each one with $100d$, it is not possible to say that d_j is at the right of d_k or d_k is above of d_j, and so on. Consequently, unlike amounts, quanta are only cardinal-countable and cannot even be particularized because its non localizability.

Quanta in this sense would be the apposite of a trope[15], so to speak, a concrete, non-particular, non-localizable in space or time. At this point, Seibt achieves a dynamical ontology that goes around the substantialist picture. The question now is: Could free process achieve a reasonable description of the quantum entities?

At this point, Seibt suggests that her approach reveals "[. . .] conceptual affinities between APT and the Fock space formalism of QFT" (SEIBT, 2002, p. 90). Many issues are present in such a proposal. For now I will only consider her exposition; in the next

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[14] Quanta states here for an ontological category and not by its homonym from quantum physics.

[15] Remember that tropes are abstract particulars localized in space and time.

section I will make major consideration about the plot intended by her. Remember that the Fock space formalism is used only in free QFT. As it will become clear, and she herself affirms, "[. . .] the primary aim of the considerations presented here is to assist rather than to present research on the ontological interpretation of QFT" (SEIBT, 2002, p. 93).

> In APT a complex free process (e.g., a blizzard, a fugue, the stock market) is the interaction process of component processes, e.g., the interactivity* Q of component activities* $\beta_i : \alpha = In\langle\beta_i, \beta_2, ...\beta_k\rangle$. As a dynamic 'mixture' of dynamic 'stuffs' a complex process might in particular be a superposition of activities* (i. e. dynamics which can be represented as the harmonic modes of a classical field). Assume then, as above, that an amount of α is described in terms of a list d-quanta* of the $\beta_i, [\alpha] = \langle q_1(\beta_1), q_2(\beta_2), ...q_k\beta_k))\rangle$, and that such quanta* have discrete values. For any measurable property A of the β_i we can then determine a distribution patterns of A within α representing $A-quanta$* of the β_i in terms of their discrete values: $F_A = \langle n_1, n_2, ...n_k)_A$. Under the given assumption a complex process α thus can also be represented in terms of a list of distribution pattern F_d for any measurable property d of the component activities* of α. (SEIBT, 2002, p. 91)

She makes additional remarks on the measurement problem.

> A quantum* of β is the indeterminate antecedent stage of a specific measurement process for a measurable property on an amount of β. In APT a quantum* of β can have indefinite value $(n'orm')$; in this case it is the indeterminate antecedent stage of an inspecific measurement process (e.g., characterized as the disjunctive process of *measuring for* d_1 *or measuring for* d_2, or as the disjunctive process of *measuring* n *for* d_1 *or measuring* m *for* d_1). (SEIBT, 2002, p. 92)

From the quotations above we can extract all Seibt's main remarks on the measurement process and their possible use in QFT (or QM). First she makes use of a "formal" approach to her own ontology by describing the quanta (properties) of an amount as having discrete values. Clearly, quanta is a part of an amount of some stuff. If such stuff can be divided into amounts, then it is possible to define a measurable property for that amount in terms of quanta.

If we take again the example of a cup of coffee perhaps Seibt's proposal becomes clearer. The coffee is the stuff and the coffee in the cup is the amount, and the possible unities used to divide the amount of coffee are quanta. This quanta are defined in terms of the coffee property to be considered. Now, if we define a property A and divide it in two equals quanta, d_i and d_i, then it is still impossible to say which quanta is which. It is not possible to define one quanta relatively to the other because they are "superposed" in the amount. Only when one separates part of the amount with one of those quanta is that we can say which is which relatively to each other. Note that it is still impossible to say which quanta we get, after all, they have the same values.

From this point forward, Seibt does not provide any additional hint that could help us in understanding her proposal. However, we will make a try because it seems that there is a fruitful insight here.

Now, if we ignore the analogy and focus on the measurement problem itself, it seems that Seibt is providing a way to describe a superposition.

Loosely speaking, in a superposition the eigenstates of an operator (observable) are in a linear combination. The eigenvalues of the spectrum operator are the possible outcomes of a measurement. Before the measurement only the probability of obtaining some specific values is given. It seems that this is the kind of situation intended to be described in Seibt's ontology.

The cup can be viewed as the operator while the amount of coffee is the spectrum. The property of the coffee to be divided into quanta defines the kind of observable. If we divide the amount (spectrum) of coffee into two units or even a milliard of equals quanta, then it is still impossible to distinguish one quanta from the others. Only when we take an amount of coffee representing the quanta out of the cup (measurement) is that we obtain an specific quanta (eigenvalue).

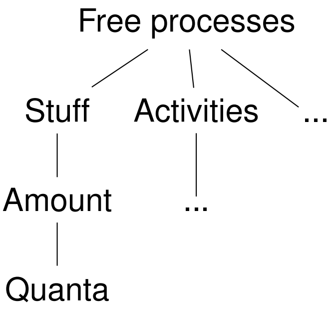

Table 10 – Seibt's framework for quanta

After all, it is unclear the real meaning of Seibt's ontology in the quantum domain, however it is impossible to deny the real attention paid by her towards the development of such an ontology.

Above all, the main result of her proposal is the concept of *quanta*, which is an homomerous individual, non particular and only cardinal-countable (a free process). It seems that Seibt's proposal intends to conceive quanta as a possible candidate to perform a description of many aspects of the quantum domain. The first one is to assume quanta as a possible candidate to the role of the values to be obtained in a measurement. Since before any measurement in QM all the eigenvalues in the spectrum operator are in superposition, one could use the concept of quanta to model such a situation. Thus, quanta, that are similar to the possible outcomes of a measurement, would be cardinal countable, non-particulars and with the disposition to become individualized without becoming particulars.

4.6.1 Critical remarks

On one hand, process ontology has the potentiality to become a powerful approach to physical theories involving fuzzy entities represented by quantum fields. Free processes reject several classical assumptions about ontological categories, becoming a great candidate for an ontological approach on the quantum domain. On other hand, as we can see it from Seibt's approach, there is a lot more work to be done before processes become a reliable category for the description of physical theories.

After all, Seibt does not provide many examples about the application of her ontology on the quantum domain. Her direct concern is to afford an ontological description for the measurement problem, however, all that remains after her exposition is just an analogy. Clearly, as she herself affirms, her proposal works more as a schema than a real interpretation for QFT.

4.7 FINAL REMARKS

While Auyang is triyng to grasp the ontological description direct from the mathematical definition, Seibt's move lacks of real connection with the theory but is compensated with a well-developed category.

The major merit of Auyang's approach is provide a faithful analysis of the components that are essential for the ontology envisaged by her according to a specific formulation of QFT. However, there is a gap between the attention paid by her to the formal aspects of the category of events and the mathematical structures underlying QFT. There is a clear unbalance between formalism and ontology in her approach, what makes the event category becomes just a label for part of the formalism. On other hand, even containing many useful insights, Seibt's approach is unable to offer a solid bridge between ontology and QFT.

In conclusion, while Auyang reveals how crucial are the mathematical structures for the formulation of ontologies, Seibt indicates the importance in having meaningful ontological categories in describing the physical theories. In the end, it seems that one approach complements the other.

5 CONCLUSION: MAKING ONTOLOGY

5.1 OVERVIEW

As we have said at the beginning of this thesis, this work is about the role of ontology in describing the physical theories, especially those belonging to the quantum domain. In particular, we have paid close attention to the possible steps that could help us in developing ontological frameworks for the working ontologist in physics. In this sense, my first intention was not to be committed with any specific ontological model and neither to provide a new one, but just to examine the different paths that could be taken in formulating such ontologies. Clearly, I do not deny that the appraisal of different ontological frameworks provided ways to enhance the deflationary approach defended here. Such an approach propitiated several results. Properly, the deflationary approach can be read in a two-folded sense. On one hand, as a meta-meta ontological approach towards ontology of physics. On the other hand, as a methodology oriented to delineate the general lines for the formulation of ontologies for physical theories.

Furthermore, the very notion of a methodology for ontology of physics was conceived here in a sense that is broader than usual. Simply put, our methodology consists in contrasting different methods used in ontology of physics with factual cases taken from different physical theories. In accordance with the deflationary approach, the general lines envisaged here for the development of ontologies are consistent with the idea that the ontologies should been build up only around the physico-mathematical structures present in the physical theories.

After all, more than a dispute about the most suitable ontologies for a physical theory, the main result was the general assumption that the degree of reliability of the ontologies relies on the study of the structural features of the theories.

Finally, I would like to suggest a way to apply the deflationary method in the ontological analysis of physical theories. In the next section the main lines for a categorial analysis in QFT are set out.

5.1.1 Categorial analysis in physics

Categorial analysis establishes a secure path for the ontologist envisaging the setting up of ontological categories, however, as we have seen, this strategy is not so effective when one is trying to provide an ontological approach for a given physical theory.

In this section my idea is to apply the categorial analysis to give sense for the possible ontological categories that one could choose or formulate in describing a theory. Notice that we are not suggesting one ontological model, but just reading the physical theories from a structural perspective with the intention of framing the adequate ontological categories for the descriptive job.

Well, after comparing several ontological approaches to QFT one conclusion is possible. One-category ontologies like those presented by Auyang and Kuhlmann, although based on the mathematical counterpart of the theories, entail in just one privileged physico-mathematical structure, thus pushing the theories towards some specific ontologies. That is why the identification of the main structures of a theory may afford us with ontological models more coordinated with the theories.

Consequently, ontology of physics cannot neglect the importance of the mathematical structures which furnish a solid grounds for QFT. From this perspective, I am proposing that before take into account the categories at hand, we should observe the theory itself in order to identify which elements may be considered in developing the ontological categories. Clearly, it would be a mistake to assume some conceptualist view about the theory itself and to propose that every mathematical element has some ontological counterpart.

Following all that, it seems that an example may illustrate what I am trying to say. Properly, I have chosen the QFT as an example of a physical theory that could be described by some ontology. Obviously, there are many problems in saying that because, in fact, there are many quantum field theories and none of them is a well delimited domain of discourse. However, whether QFT is a theory or a bunch of theories does not invalidate the fact that it is the main physical theory at our disposal nowadays. Above all, QFT succeed. So, let us take a look inside the theory to see the main lines of its construction and try to read these aspects in order to indicate what steps the ontologists in physics may take to formulate theirs ontologies.

5.1.2 Example: Categorial analysis in QFT

QFT solves many problems and this is only possible by making use of several mathematical structures. The total of this formal apparatus can be divided in two main blocks working together. On one hand, we have the algebraic structures of the theory, what includes the equations whose invariance is preserved by other elements, such as operator algebras and group structures. On the other hand, we have the metric structures in which parameters are defined in a spacetime structure. The interplay of this two structural sides permits the theory to encapsulate all formal features that characterize the entities and theirs relations.

As we know, the spacetime structure of standard QFT is generally defined as the flat Minkowski space in terms of SR[1]. In this structure all events are divided into three kinds of relations: lightlike, timelike and spacelike events. This three types of spatiotemporal relations define crucial features of the entities in QFT.

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[1] See Appendix C, Section C.1.

In QFT the kinds of entities, i.e. their classes, are defined according to group representation, meaning that the properties of the entities in QFT are defined in terms of group structures ruling the representative operators in the theory. Furthermore, other aspects of QFT, like interaction, involve elaborate mathematical structures as fields. Properly, the interaction is only possible when those fields *share* not only parameters in spacetime, but other structures as well. As we have seen[2], the local symmetry group transforms the interaction potential and the phase of the matter field simultaneously, preserving the invariance of the interaction system. This is only possible because the principal bundle shares "its" group structure with the associated bundle, and, then, permitting the coupling of the matter field and the interaction field.

Thus, it seems that is necessary an attentive study of those structures to make ontology in QFT. Here I am not proposing any specific ontological model for QM, but just suggesting the methodological lines to achieve a faithful ontological description of the contents for this specific theory. Clearly, the headlines outlined here could be extended to other theories as well. To given an example, right below I suggest a brief view of the general lines of an interaction and the main features to be considered in its ontological analysis.

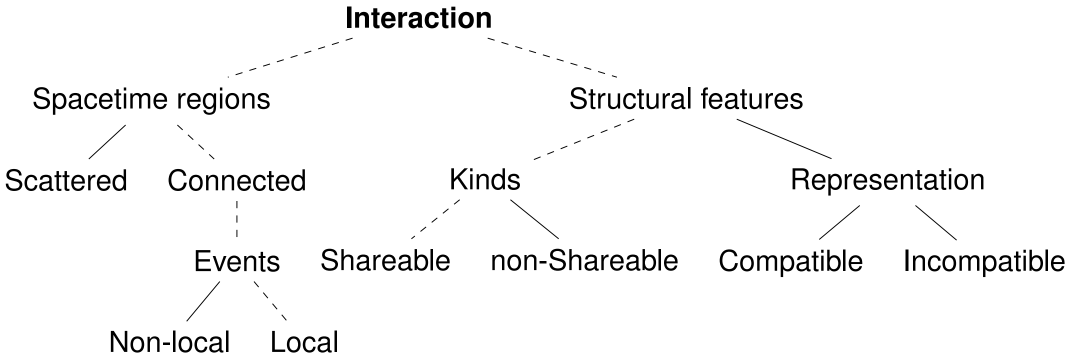

Table 11 – Main lines for a categorial analysis of an interaction in QFT

The dashed lines in the schema above represent the main features that allow the occurrence of an interaction. Remember, an interaction is a local (local) phenomena that presupposes a timelike (connected) interaction to preserve micro-causality. In order to occur the interaction coupling both structures must share (sharable) the same group structure (gauge group).

Different from an interaction, a commutation relation in QFT requires operators acting on spacelike events in the spacetime structure. In this case the operators are required to be compatible (compatible). Such a compatibility depends on the specific observables at stake, which are still defined in the structure of the theory; such structures are those involved in the representation[3] (representation) of the possible properties of

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[2] See Chapter 4, Section 4.3.1.

[3] In the sense of Representation Theory. See (WIGNER, 1939)

the entities.

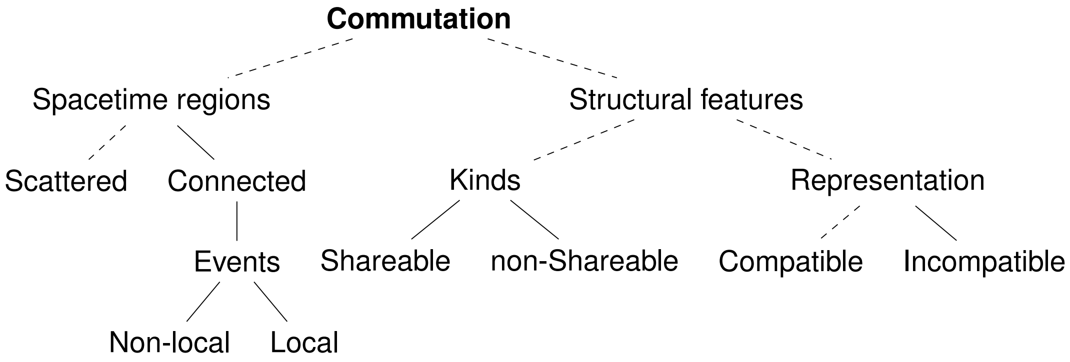

Table 12 – Main lines for a categorial analysis of two commutating observables in QFT

The purpose of these schemes is to motivate the idea that physical theories furnish positive contents to the construction of ontological models, and more than that, not just as providers of structural features that must be passively observed by the ontologists, but also as providers of the general lines for the ontologies to be set up. Notice that this procedure does not involve the recourse to the physical phenomena or any realist or anti-realist assumption, what is in fully accordance with the deflationary view defended here.

5.2 FINAL REMARKS

The misleading presupposition that ontologies can be about physical phenomena lead us erroneously to enhance some form of correspondentist. This perspective imprison us inside an ostensive interpretation of the role of ontology, leading us consequently towards the debate realism/anti-realism. As we showed, such a debate can be put on hold by means of what we called a “deflationary meta-ontology”.

The deflationary meta-ontology suggested here, which is not a realist and neither an anti-realist approach towards physics, defends that the debate between realists and anti-relists in physics must be suspended when the construction of ontologies is at stake.

Accordingly, our main argumentation through this thesis was against the thought that ontological models (material ontologies) are required to be set up in line with the physical phenomena. In addition, we attacked the conception that ontological models for scientific theories should be used to justify realistic or anti-realistic assumptions about some hidden reality. This correspondentist task attributed to ontology in physics is considered here as equivocate after all.

Clearly, there are justified metaphysical assumptions about the relations between physical theories and physical phenomena, which consists in genuine philosophical problems such as truth-making, agentive construction of theories, and so on. However, the widespread idea that ontological models for physical theories can be generate having both physical phenomena (domain of reference) and physical theories (domain of discourse) as object of analysis is a misconception. Mainly because assuming that ontological models can go beyond the physical theories is to assume a transitivity between physical phenomena, physical theories and ontologies; apparently such transitivity does not exist[4]. As said, ontologies are metaphysically undetermined by physical theories, not by the physical phenomena.

Furthermore, to assume a correspondentist perspective about the relationship between ontology and phenomena would lead us again towards an ostensive model of language, which always imply the idea that any domain of discourse is a *medium* towards the domains of reference. This view get us the wrong idea that physical theories cannot provides us with all the elements necessary to theirs description. Actually, what becomes clear is that the physical theories provides us with all necessary elements to define the ontologies associated with them. After all, those theories have a positive function in the definition of ontological categories.

Consequently, we are not supposing that there is some sort of “final” ontology for the physical theories, and the main reason for that is that there is no final physical theory in the domain of physics. An ontology in this domain must be able to adapt itself to the changes in the theories. If a theory change, then the ontology must also be changed; if the theory fails then the ontology associated with it is no longer needed[5].

In this sense an ontology for a physical theory is just one possible candidate among others. By choosing a different physical theory a different ontology might be implemented. In front of the developments of the physical theories theirs ontologies are required to be open to modification, being passive to be restrained or spanned, or even be abandoned. By putting aside the presupposition that ontology mirrors reality implies that any chosen category can be modified, aggregated, replaced or excluded from the ontology according to modifications in the physical theory itself. This way, an ontology for a physical theory is not a final view about reality but just an adequate view about what the theory says.

5.2.1 General results

In the long run, many other results were achieved and the several outcomes of the present (meta-meta)ontological investigations can be resumed as follows.

i) A one-category ontologies seem to be not enough to deal with all aspects that emerge from a physical theory. In order to exemplify this statement, we have

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[4] See Chapter 1, Section 1.5.1.

[5] See Chapter 2, Section 2.1.5

already showed how different ontological frameworks for QFT have failed or were insufficient to fulfill all requirements stated by an ontology for QFT[6].

ii) An ontology that pretends to be, at least, almost coherent with the theory must observe, before anything, the physico-mathematical formalism that defines one theory.

iii) In this sense, it seems that an ontology for a physical theory must be plural regards its ontological categories and mathematical structures, without privileging some of them.

iv) Although it is possible to conserve the concept of substance in several situations, our investigations pointed out that there is no need for the classical substance picture in an ontology for the quantum domain[7]. The strategies to fly away from this paradigm goes in two directions:

a) It is possible to create an ontology that uses categories that simulate themselves as substances, but they are not substances after all. Notice that while substances are unalterable from the ontological point of view, other categories may act as "pseudo-substances" by preserving an structure that performs the theoretical role of substances[8].

b) It is possible to generate an ontology whose categories are not committed with substances and still preserves traditional notions as individualization[9].

v) An ontology for a physical theory does not need to be part of an ontology much more comprehensive, which could contains considerations about structural features and entities that do not belong to a given physical theory. With this view we go against traditional supporters [10] of the idea that only a single ontology/metaphysics can be used to describe entities of different (all) domains.

vi) Mostly of the ontologies projected onto the quantum domain pay little attention to the structural aspects of the theories. Although there are ontologies that deal with those aspects, they fail in the fully connection between theirs ontologies and the theories[11]. This occurs by three main reasons:

a) Ontologies seeking the structural aspects of the theories (Kuhlmann and Auyang), in large extent, neglect several features of the specific formulations of the theories. In general, they give preference to some structural elements, while

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[6] See Chapters 1 and 2.

[7] See Chapter 2, Section 2.2.

[8] See Chapter 2, Section 3.4.1.

[9] See Chapter 4, Section 4.5.0.1.

[10] (ARMSTRONG, 1997), (SIMONS, 1994), (SEIBT, 2002).

[11] (KUHLMANN, 2010), (AUYANG, 1995), (SEIBT, 2002)

leave out others. This occurs even when the structures set aside are not surplus structures[12].

b) The privilege that some category may receive in a ontology is the reason why some structures are preferred in front of others, which is the case in Kuhlmann's and Auyang's proposals each. This occurs because most part of the ontological approaches are monocategorial. In this case, the category chosen is attached to some privileged structural feature.

c) Some ontologies almost equalize the structural features of the theories with the ontological categories envisaged by them. in this case the object of description is assumed to be as the same as the category. After all, these ontologies just label a concept in the theory with the name of a category. Namely, the difference between concept and meta-concept is lost.

vii) The formal approaches examined here are an example of how ontologies dealing with different aspects of the quantum domain are insufficient to obtain formalized ontologies in a more precise way. The complexity required by an ontological framework in the quantum domain goes far beyond the approaches dispensed up to now.

In the end, it seems that the "negative" results of negate the debate between realists an anti-realists are surmounted by the positive results in assuming a deflationist perspective. I believe that the major result of this thesis was to show how methodology is important for the definition of the role of ontology in physics. Whether the present methodological proposal is fruitful or not is something to be decided, however, what becomes clear after all is that ontology needs to read the physical theories and not to write them.

> Try to take science on its own terms, and try not to read things into science. If one adopts this attitude, then the global interpretations, the "isms" of scientific philosophies, appear as idle overlays to science: not necessary, not warranted and, in the end, probably not even intelligible. (FINE, 1984, p. 62)

The deflationary approach defended here is an alternative to the traditional idea that the triad phenomena-physical theories-ontologies is an unavoidable fact for the ontologist. Such an approach showed how ontologies are not connected with the presupposition that they must serve to the purpose of mapping concepts into the world. Above all, ontologies are directed just towards the physical theories, and more than that; they, the theories, provide us with all the necessary content for the ontological description of the entities of physics.

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[12] Remember that we are not assuming any distinction between "good" and "bad" structures by means of a subterfuge as surplus structures.

In the end, I hope that this thesis might help in the methodological (meta-ontological) choices of anyone concerned with the same matters discussed here.

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Appendix

APPENDIX A – QUANTUM THEORIES

A.1 WHAT IS THE QUANTUM DOMAIN?

What is the quantum domain? We cannot answer such a question without falling into some kind of metaphysical *petitio principii*. It occurs because one may assume before anything else that there is a well defined domain to be investigated. However, things do not happen that way on the quantum domain. Actually, “quantum domain” is just a void name to characterize a bunch of different physical theories, or pretending ones, orbitating around the word “quantum”. Non-relativistic Quantum Mechanics (QM) and Quantum Field Theory (QFT) form the two main blocks denoting a variety of quantum theories.

So, “Quantum Domain” is just a generic name for many quantum theories or formulations of these theories. Such theories can be differentiated among themselves by means of several features, like experimental success, range of application, axiomatic formulation, formalization, interpretations, simplicity (in some sense), and so on.

A.2 MANY QUANTUM THEORIES

There are relativistic theories and non-relativistic ones, such as QM and QFT respectively. In addition, there are Relativistic Quantum Mechanics (RQM) and QFT with non-relativistic solutions. There are axiomatized theories, or at least quantum theories based in general postulates. On the other hand, there are quantum theories that justify their existence just by its experimental success. Some theories are more limited than others. After all, there is a widespread crop of quantum theories. Consequently, many approaches could be mentioned here, however just a panoramic view on them is enough to illustrate the real range of the quantum theories.

Quantum Mechanics (QM)[1] - just like any other physical theories - is about something; it is about entities of some kind. Above all, QM is a successful physical theory, providing a clear way to represent and predict the behavior of the quantum particles on its scope.

In QM a *physical system*, depending on what one wants to represent, can be a single quantum entity (single) or a many-system of them. In QM various quantum entities and phenomena can be represented by means of adequate equations. Such equations are the result of many hands and its development is a totally separate history[2] that we will not deal here with.

Neither all known particles are described by QM. Several particles such as photons cannot be predicted according to the physical laws and equations accepted by

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[1] Here we consider only non-relativistic quantum mechanics in the Hilbert space formalism. For different formalizations in QM see (STYER et al., 2002), for interpretations see (JAMMER, 1974).

[2] See (JAMMER, 1974), (KUMAR, 2008), (WEINBERG, 2013).

QM. Thus, extensions or even new quantum theories are required; which is the case of QFT as well.

The first and most basic view about QFT is the *free field* approach, which does not hold interactions in the dynamics. This "simple" view about QFT can also be called *non-perturbative* QFT. Unlikely, perturbative QFT originates inside non-perturbative QFT. Roughly, is a theory where interaction is conceived as perturbations around a point in a free field. Such procedure results in many issues for the perturbative formulation, which are solved by approximated methods. Properly, perturbative QFT is part of non-perturbative QFT.

QFT has many formulations, some of them are well founded in axiomatic approaches, or at least based in well defined mathematical structures such as Topological Quantum Field Theory (TQFT), Axiomatic Quantum Field Theory (AxioQFT), or AQFT. However, from the pragmatic point of view, those formulations cannot deal with the real phenomena that the theory should describe or predicted. Thus, many physicist have put aside the need for axiomatizations or well-founded formulations of the theory in order to make sense of calculations in *effective quantum field theories* as the Heavy Quark Effective Theory (HQET). These formulations just apply the methods of prediction without concerning about foundation problems.

Quantum Field Theory is the result from Dirac, P. Jordan, Heisenberg, Born, Pauli and many others[3] effort for the merger between QM, Special Relativity (SR) and Classical Field Theory (CFT). As we shall soon see, SR is essential[4] to elaborate a physical theory able to investigate the existence of relativistic mass, while CFT is the natural framework for the representation of particle interaction. From that, QFT can model annihilation and creation of particles in contexts involving an unknown number of particles, which can be accelerated at speeds approaching the speed of light. Actually, QFT was not a "unique" theory until the sixties, when the nowadays *Standard Model* was conceived by the effort of several hands. After that, QFT could be viewed as a single theory. However, this does not mean neither clarity nor unity after all, because depending on what one wants to investigate "one" QFT will fit better than others[5]. Up to now, the standard model has achieved great success by its predictive power, which highly overcomes any other physical theory at hand.

Historically[6], QFT have many stages, going from relativistic quantum mechanics until the standard model. This way QFT have passed by Quantum electrodynamics

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[3] For a historical account (WEINBERG, 1995).

[4] There are different formulations for QFT than those considered here. For instance, the Osterwalder-Schrader formulation shows how QFT can be elaborated in the Riemmanian manifold instead the Lorentzian manifold, implying that locally the spacetime structure does not need to be the Minkowski spacetime. See (HAAG, 2012, p. 323).

[5] "[W]e should recognize that the standard formalism of quantum physics is not sacrosanct and will probably be modified in future theories." (HAAG, 2012, p. 322).

[6] For a historical and constructive view of QFT, see (WEINBERG, 1995), (SCHWARTZ, 2014).

(QED), different attempts of axiomatization, Feynmann's integrals, Yang-Mill's theories for strong interactions, the unification of the electromagnetic and weak interactions by Glashow, and the explanation for the Higgs mechanism made possible by Weinberg and Salam.

Both QM and QFT have many different formulations. So, it is difficulty to achieve an unified view about what makes each one a physical theory *per se*. Below I present a partial sketch of how QM and QFT are unfolded among different formulations and interpretations.

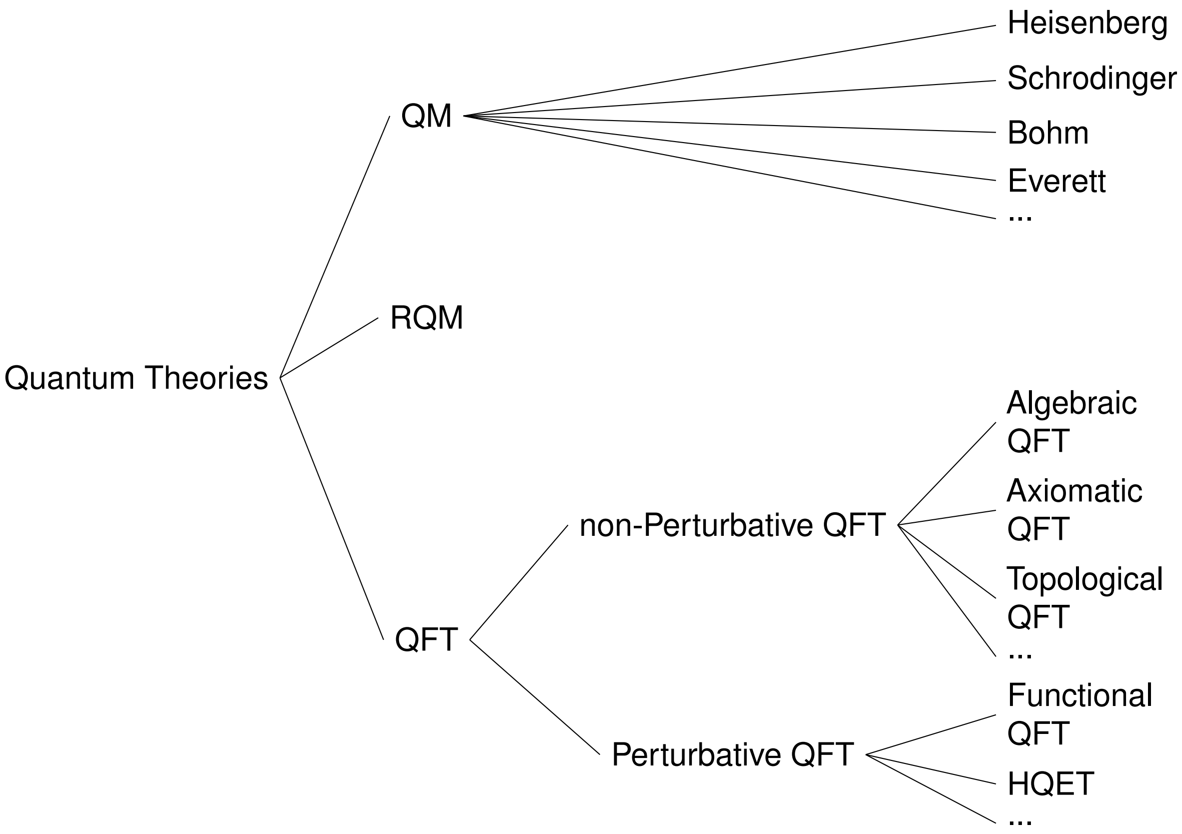

Table 13 – Quantum theories

APPENDIX B – QUANTUM MECHANICS

B.0.1 QM in Hilbert space

Basically, there are three essential features of a physical system in QM: the *physical system* (system) itself, the “properties” of the system called *observables*, and the possible physical outcomes of the system usually called *states* of the system. These features can be represented in the usual mathematical formalism of QM: the Hilbert space formalism. Such a formalism was developed in 1932 by von Neumann in order to organize and encapsulate the dispersed views provided by the Heisenberg matrix mechanics (1925) and Schrödinger wave mechanics (1926). Later both formulations were proved equivalent by him[1].

In the Hilbert space formalism, a quantum physical system is represented by a n-dimensional complex Hilbert space, $\mathcal{H}$, while the observables (dynamical variables) and physical states (dynamical quantities) related to that system are represented by self-adjoint linear operators, O, and unitary vectors, $|\psi\rangle$[2], in $\mathcal{H}$, respectively[3].

A Hilbert space is a rich structure that has many concrete representations. Two of them are the spaces $\mathcal{L}^2$ and l^2. More specifically, Schrödinger used $\mathcal{L}^2$, the space of the *square-integrable function*, while Heisenberg made use of the l^2, the space of all one-column complex matrices[4]. Since $\mathcal{L}^2$ and l^2 are both separable and infinite-dimensional they were proven later to be isometrically isomorphic by von Neumann.

B.0.1.1 Observables and physical states

In QM any observable is represented by a *self-adjoint operator* or, the same, a Hermitean operator. Such operators have four essential features for QM: i) their eigenvalues are all real; ii) if these eigenvalues are different among them, then their eigenvectors are all orthogonal; iii) the eigenstates form a complete set of basis states for the *state space* of the system; iv) the eigenvalues of these operators are the possible values of the measurement of an observable. Thus any possible value that an observable can obtain is an eigenvalue of the self-adjoint operator. Such a relation can be described by the so-called *eigenvalue equation*:

$$O\,|\psi\rangle = \lambda\,|\psi\rangle$$

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[1] See (CASADO, 2008, p. 154-155), (JAMMER, 1974, p. 22).

[2] Here represented in Dirac’s braket notation (KRAUSE, 2016, p. 47).

[3] As demonstrated by (WICK; WIGHTMAN; WIGNER, 1952), in contradiction with Dirac-von Neumman formulation for QM, neither all vectors and neither all self-adjoint operators correspond to states or observables.

[4] See (KRAUSE, 2016, p. 36-37), (PRUGOVECKI, 1982, p. 33).

where the action of the operator O upon a vector $|\psi\rangle$ is equal to the scalar multiplication of the vector by the correspondent eigenvalue λ in the spectrum of the operator.

In this case, $|\psi\rangle$ is called an eigenstate of the operator O, and the set of eigenstates associated with the operator is an orthonormal basis for the *eigenspace*. In QM such space is the *space state* associated with the operator O[5]. To summarize, since a physical system can assume different physical states at different instants of time, all these possible states give rise to a state space or, the same, a *phase space*[6], which has the structure of a (complex) Hilbert space[7].

A linear operator is said *non-degenerate* if all eigenvalues of the operator are different. In contrast, if the operator has repeated eigenvalues, what means that different eigenstates are associated to the same eigenvalues, then the operator is said *degenerate*. For instance, in QM it means that a physical system can have more than one state (eigenstate) associated with the same energy level (eigenvalue). In this case, we say that the system has degenerate energy levels.

Unlike classical mechanics, in QM some observables cannot be measured simultaneously. If two operators representing two different observables for the same quantum system can be measured simultaneously and with great precision, then we say that the operators *commute*; or the same, the observables are *compatible*. By the same reason, two observables that do not commute are said to be *incompatible*. Such a situation is described by Heisenberg *Principle of Uncertainty*, which states that in QM some observables are always incompatible.

The main idea is to describe what happens to a quantum system during a measurement of two incompatible observables. For instance, when one wants to know the position of a particle α moving in the space (what can be just in one dimension), we need to consider the momentum λ_i of that particle. Both, momentum and position are represented by self-adjoint operators. In order to obtain an accurate measurement about the particle's position we need to hit the particle with some laser beam or radiation whose particles γ must have a momentum λ_j bigger or equal to the momentum λ_i of α. This means that when we measure the position of α, whose momentum is smaller than γ, we affect directly the momentum by making a momentum transference. In this case,

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[5] Actually, $|\psi\rangle$ is a unitary vector picked over a ray (1-dimension subspace of $\mathcal{H}$), the choice of a vector on the ray is arbitrary since such vector can be multiplied by a phase factor λ, usually taken to be the phase factor $e^{i\theta}$, without changing the state. The action of the phase factor on the state is irrelevant, unless in the case of a superposition of states. All this happen in a specific $\mathcal{H}$ know as *Projective Hilbert Space*, where the *projective operator* fixes equivalence classes by means of the relation $v = \lambda w$, where $\lambda \in \mathbb{C}$ and $v, w \in \mathcal{H}$.

[6] See (AUYANG, 1995, p. 17).

[7] Another way to see the relation between the Hilbert space formalism and the phase space is by using fiber bundle theory. For instance, the space $\mathcal{L}^2$ acts on a set X, which is the configuration manifold of the physical system. For each point x in the configuration manifold there is a tangent space on that point that represents the possible states of that system. Consequently, the tangent bundle of X is the phase space, which has the structure of $\mathcal{L}^2$. About the domain of $\mathcal{L}^2$, see (AHIEZER; GLAZMAN, 1993, p. 21, note 14).

while we get a more accurate position we lose its momentum. The same goes for the momentum measurement, since more accurate is the measurement of the momentum mode widely scattered is the position (GRIFFITHS, 2018, p. 17-19, 108–111). Consequently, the representative operators of those observables do not commute[8]. The more accurate the measurement of one of the observables more uncertain the measurement of the other is; this situation is described by the uncertainty relation:

$$\sigma_x \sigma_p \geq \frac{\hbar}{2}$$

where σ_x and σ_p represent the observables, while $\frac{\hbar}{2}$ represents Planck's constant, h, divided by 2π[9].

In particular, position and momentum require a system with an infinitely number of quantum mechanical dynamical variables; infinite degrees of freedom, for short. Consequently, they have continuous spectra, being impossible to obtain any (infinitely) precise value for any those observables. Properly, position x and momentum p_x are said to be *canonically conjugated* observables, which means that they never commute according to the following relation.

$$[x, p] = xp_x - p_x x = i\hbar\delta_{i,j}$$

This relation is called the *canonical commutation relation*, and it is a fundamental relation in QM. Where $i = \sqrt{-1}$ and $\delta_{i,j}$ is the Kronecker delta with $i \neq j = 0$ and $i = j = 0$. This relation states the idea that incompatible observables never share one only complete set of common eigenvectors, which means that operator (matrices) representing incompatible observables never can be simultaneously diagonalized.

B.0.1.2 Dynamics and probability

In wave mechanics $\mathcal{H}$ is represented as a function space where the observables are represented by differential operators, and the states are represented by complex

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[8] The operator algebra that governs such features is know as Heisenberg Algebra, a non-commutative Lie algebra.

[9] Such division is made in order to quantize the angular momentum.

functions; more specifically, these functions are called *wave functions*. The temporal evolution of a state $|\phi\rangle_i$ is given by the time-dependent[10] Schrödinger wave equation:

$$i\hbar \frac{\partial |\phi\rangle}{\partial t} = H |\phi\rangle$$

where H is the Hamiltonian of the system. Depending on the specific system both the linear operator and the Hamiltonian must be changed. Actually, the wave function does not represent a physical state, but gives the probability to obtain a certain value in the measurement of a physical system. This way a wave function $|\phi\rangle$ is defined as a *complex-valued probability amplitude*. It is complex because $\mathcal{H}$ is a complex space, but the exigence that it must involve some kind of probability requires that the space to be the $\mathcal{L}^2 X$. In $\mathcal{L}^2 X$ is possible to obtain the density probability of measure a quantum system in a given state. It is represented by the *normalization condition*,

$$\int_{-\infty}^{\infty} |\psi(x,t)|^2 dx = 1$$

which states that the probability density to find, for instance, a particle in a given point is proportional to the square of the magnitude of the wave function over *that point*. Eventually, all we can obtain is just the probability to obtain some value in the phase space.

B.0.1.3 Types of states

Depending on the physical system a quantum state can assume additional aspects than those presented above. Thus, a quantum state can be classified in several ways.

Pure and mixed states - QM relies on probability and all quantum contexts are involved in some level by this feature, however, the way a physical state can be described according to its possible outcomes after a measurement is miscellaneous. Before a measurement we never know with certitude which values the measurement may take, but there is two emblematic situations in this case.

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[10] QM can be formulated in many ways, but when we consider the role of time in the theory, we can be involved by two main forms to deal with time: the Schrödinger *picture* and the Heisenberg *picture*. The Schrödinger *picture* considers the wave function as time-dependent, while the operators remain fixed. On the other hand, the Heisenberg picture takes the operators to be time dependent, while the wave function is considered time-independent (GRIFFITHS, 2018, Chapter 2). More than a matter of taste (KUHLMANN, 2010, p. 213), the option for one or another has significant outcomes (PERES, 2006, p. 243).

First, among a certain number of possible outcomes (eigenstates) that a physical system may take, we have only the probability that a physical state will *collapse*[11] in one specific eigenvalue. Anyway, we know with total certitude that the system will collapse in one of those states. When is possible to know before any measurement all the possible outcomes for the state, we classify the state as a *pure* state. This way, a pure state is a state that contains all possible information about the system before the measurement. In this case the state is represented by a unitary vector in a 1-dimensional subspace of $\mathcal{H}$, which carries maximal information about the system. Any pure state can be represented as an element of $\mathcal{H}$. If it is not possible, then the state is said to be a statistical mixture or *mixed state*.

A mixed state is a *mixture* of pure states, which is a probability distribution over the individual possible states. That is why we called it *statistical ensemble*. Unlike the pure states, a mixed state cannot be represented by a unit vector $|\psi\rangle$, but just by an operator called *density operator*. In a mixed state we do not have all the information about the possible outcomes for the system. Furthermore, in general, a mixed state is a state in which we do not have all the information about the state involved in the measurement or about the preparation of the system. By taking the individual probability for each state we can write the density operator ρ in the matrix form as follows:

$$\rho = \sum_i w_i \, |\psi_i\rangle\langle\psi_i|$$

where w_i are the individual probabilities taken as coefficients for the *tensorial product* $|\psi\rangle \otimes |\psi\rangle$ written above in bracket notation.

Different situations can be described as pure or mixed states[12], here we cannot make a long analysis on this matter. But, we will present some paradigmatic examples that involve both features.

Superposition - One important feature of the vectors $|\psi\rangle_i$ that represents the state of a physical system is that they can be written as a linear combination of other vectors,

$$|\psi\rangle = \sum_{i=1}^{n} a_i \, |\psi_i\rangle$$

This combination is usually called a *superposition* of states, which is still a vector representing a state - a superposed one. In QM a *superposed state* occurs when there

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[11] For all matters, we always consider QM with the Collapse Postulate.

[12] Actually, any pure state can be represented by a mixed state of rank-1.

are two or more possible states that a system may occupy. For the sake of example, the spin values of an electron. Since an electron can have two opposite states relatively to its spin, spin up and spin down, we can represent the superposed state as a sum of the two (orthogonal) states:

$$|\psi\rangle_{12} = |\psi_{up}\rangle + |\psi_{down}\rangle$$

Entanglement - Another type of state is the *entangled state*, which can be pure or mixed. Two or more particles are entangled when the state of one particle cannot be described independently from the state of another one. In the formalism we write this relation by means of the tensorial product of two (or more) vectors $|\psi\rangle$ and $|\phi\rangle$, each one belonging to two different[13] Hilbert spaces, $\mathcal{H}_1$ and $\mathcal{H}_2$, both representing the different physical systems. For two physical systems in a entanglement we can write:

$$|\psi\rangle \otimes |\phi\rangle$$

where $|\psi\rangle \in \mathcal{H}_1$ and $|\phi\rangle \in \mathcal{H}_2$. In more technical terms, if the composite system (tensorial product) of those two systems cannot be decomposed in two different states pertaining to each space (subsystems), $\mathcal{H}_1$ and $\mathcal{H}_1$, then they are entangled. On the other hand, if the composite system can be decomposed, then we have separable states, which can be pure or mixed states. Thus, an entanglement is a composite system in which the different physical systems cannot have their states determined independently of each other.

B.0.2 Limitations of the quantum theories

As we saw, QM is a fruitful physical theory, having several formulations[14] and even axiomatizations[15]. Even though providing astonishing predictions and results that bypass classical physics in many ways, QM has its own limitations. Obviously, QM intends to solve some problems, but not all of them.

The limitations of QM are mainly due to the classical background of the theory. Since QM relies on the Galilean spacetime, it is impossible to the theory make major considerations on relativistic aspects of the quantum domain. Especially, since QM and SR are not compatible, the Schrödinger equation is insufficient to describe physical system at speeds proximate of the speed of light, imposing empirical limitations to the theory. Although several quantum entities can even live on its domains massless

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[13] When the composite system is composed by n indistinguishable particles, the tensorial product is written by taking the same Hilbert space n times. See (KRAUSE, 2016, p. 92-94).

[14] See (JAMMER, 1997, p. 5)

[15] See (ARENHART; KRAUSE, 2016, p. 106)

particles such as the photon do not even exist in QM. Such trace is due to the fact that interactions between quantum entities and relativistic mass cannot be represented in this formalism.

Relativistic mass is included only with the formulation of relativistic QM, and interactions become possible to be represented by the use of quantum fields, which insert locality into the formalism. Hence, interaction between particles has no place in the formalism of QM.

In addition, in the context of non-relativistic QM we can make use of Fock spaces[16] to represent creation and annihilation of a definite number of quantum entities. It is not possible to do the same thing by dealing with an arbitrary number of particles.

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[16] The Fock space formalism is applied in many situations of the quantum domain, which include relativistic contexts from QFT as well. See (FRENCH; KRAUSE, 2006, p. 374).

APPENDIX C – QUANTUM FIELD THEORY

C.1 SPECIAL RELATIVITY

In this section we just want to point out the SR's elements that are crucial for the minimal understanding of main futures of QFT. Furthermore, we are considering just the standard QFT which is generally assumed as a relativistic quantum theory formulated, as usual[1], in the flat Minkowski spacetime.

The SR is the prolific result of many hands such as Lorentz, Larmor, Poincaré, Einstein, and Minkowski. Properly, the ingenuity behind its formulation as a unified theory is due to Einstein. SR has its origins in the difficulties to conciliate Newtonian mechanics and Maxwell's equations for electromagnetism. Such obstacle has its origins in the fact that Galilean transformations (the core of Newtonian mechanics) is incompatible with the assumption that the speed of light is constant for all observers in all frames of reference.

SR came with the astonishing revision that space and time were not absolute but relative. This assumption combined with the idea that the speed of light in vacuum is constant and the same for all observers gives rise to the two principles of SR.

(i) *The Principle of Relativity or Principle of Covariance* - The laws of physics are the same for all inertial frames of reference[2].

(ii) *The Principle of Invariance of the speed of light* - The speed of light c in vacuum is constant, and independent of the relative motion of its source.

What are the outcomes of these two principles? Properly, the main problem with such a change of view is that known properties like distance and time interval, which are the same for all frames of reference in the Newtonian mechanics, become relative in a physical system with observers moving at high speed. Clearly, if we have two observers attached to different inertial frames of reference A and B, then they can observe different distances and time intervals between them. Thus, SR provides a new kind of invariant called *spacetime interval*, which is a conserved quantity between two events. However, to be invariant other kind of transformations than the Galilean transformations is required. This new group of transformations is known as *Poincaré group* (or the inhomogeneous Lorentz group[3]. This is the group of Minkowski space isometries that

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[1] QFT has many formulations, and it is not a surprise that there are approaches based on different kinds of spacetime structures as curved spacetime structures, or even Euclidean structures as well. See (NASH, 1999, p. 384)

[2] As the use of a coordinate system is something *a posteriori* in the theories, covariance leads to the conclusion that physical laws are independent from the coordinate system.

[3] See (SZEKERES, 2004, p. 55-56).

are unitary operators[4] that preserve, among other properties, the spacetime interval making it invariant for two events.

Basically, Lorentz transformations combine distances in space and in time by making the spacetime interval invariant. To achieve this task, first we need the *Lorentz factor*

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c_2}}}$$

where v is the velocity and c is the speed of light. Then the transformations can be expressed by

$$\begin{aligned} x' &= \gamma(x - vt) \\ z' &= z \\ y' &= y \\ t' &= \gamma(t - \frac{vx}{c^2}) \end{aligned}$$

First thing we must notice is that the time t and the space represented by the coordinate x are no longer considered absolute. In addition, the speed of light c is applied in the equation as a limit.

Having said that, we can return to the Poincaré group. Because it is the largest group in SR, it generally preserves only the spacetime interval, Δs. Other quantities are preserved according to its subgroups. For now we must say that by adding translations through time to the Lorentz group we get the full Poincaré group. In the full group there is basically ten degrees of freedom, which are divided into translations (four degrees), rotations (three degrees) and boosts (three degrees). All this transformations make SR possible. In short, the Lorentz group is responsible for maintaining the origin of a reference frame fixed, while the Poincaré transformations maintain some directions of a frame of reference invariant. Nonetheless, the full group is responsible for the isotropy of the system by preserving the metric of the space. Such a metric has one of the following signatures: $(-, +, +, +)$ or $(+, +, +, -)$. By choosing the former one we obtain the Minkowski metric in the tensor form:

$$ds^2 = g_{\mu\nu} dx^\mu dx^\nu$$

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[4] See (KRAUSE, 2016, p. 75-76); (AHIEZER; GLAZMAN, 1993, p. 72-73).

, where $x^\mu = (x^0, x^1, x^2, x^3) = (ct, x, y, z)$ and

$$g_{\mu\nu} = \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

So, we obtain[5]

$$ds^2 = -c^2dt^2 + dx^2 + dy^2 + dz^2$$

Thus, ds^2 is defined as the spacetime interval, which is the same for all observers even when they disagree about other quantities. The invariance of Δs is only possible by means of the Lorentz transformations. In the same sense, such an invariance is obtained for other two seminal quantities in SR: the *proper time* and the *proper length* between two events.

In this sense, Lorentz transformations come to preserve the spacetime interval between two events what is not possible by using Galilean transformations in the context of SR. The time interval is stated as following,

$$\Delta\tau^2 = \Delta t^2 - (\Delta x_1^2 + \Delta x_2^2 + \Delta x_3^2)$$

where $\Delta\tau$ is the proper time interval. The path described by a proper interval is invariant and it is called a *worldline*. The event in a worldline depends on position of the events in what is called a *light cone*.

Thus Lorentz transformations preserve spacetime interval by making invariant the proper length and the proper time between two events. It is important because we can find three interesting outcomes from Δ. In SR, the interval between two events can be classified as follows: if $\Delta^2 > 0$, then it is called *timelike*, if $\Delta^2 < 0$, then it is called *spacelike*, if $\Delta^2 = 0$, then it is called *lightlike*. This means that if we consider any two events in the light cone we will end up with one of the three situation above. More specifically, we can describe all these situations as follows:

Consider A at the origin of the light cone.

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[5] Remember that we are using the standard formulation in the Minkowski space. Einstein himself used the standard Cartesian representation by fixing $x^0 = ct$. What give us the (pseudo) Euclidean metric $x^2 + y^2 + z^2 = ct$.

$\Delta\tau^2 > 0$ - *Timelike* - The events A and B are inside the light cone, and a world line that goes from A to the event B means that the event A can affect the event B. A timelike curve γ is represented by a worldline that goes from the event A to the event B.

$\Delta\tau^2 < 0$ - *Spacelike* - The event A is inside the light cone while the event B is outside the light cone, and the world line that goes from A to B means that the event A cannot affect the event B. If it was possible for the event A affect the event B then the velocity of information would be faster them the speed of light, leading to a inconsistency with SR. In this sense we say that A and B are spacelike separated.

$\Delta\tau^2 = 0$ - *Lightlike* - The events A and B occur at the speed of light. The more closer an event goes to the speed of light smaller its proper time gets, so there is no proper time between them, what leads to form the light cone.

The type of spacetime interval is important because it makes possible to conceive a notion of causality between two events which is the main aspect of locality. Causality states that nothing can move faster then light, including any kind of information. In the end, what we have is *causality*, or the same (*Einstein causality*), that is to say, two events A and B can be in a relation of causality only if they are timelike or lightlike. In addition, A can be an affect of B only if B is at the back (past) cone light of A. Furthermore, all the events that are spacelike separated are independent and cannot affect each other since information cannot travel faster than light.

Another aspect of SR is the relation between mass and energy, what gives rise to the so-called *relativistic mass*. The relativistic mass attributed to some physical system is a quantity that depends on the velocity of that physical system, that is to say, the relativistic mass is intrinsically related with the relativistic effects. One way to obtain such values by using the relativistic mass equation, which relates mass and energy as equivalent by the so-called *mass-energy relation*. Many physicists prefer the term "total energy" rather than "relativistic mass", particularly because energy and mass are both conserved quantities in the theory and cannot be "transformed" one into each other[6].

The relativistic equation for mass can be conceived as follows:

$$m = \gamma m_0$$

where γ is the Lorentz factor and m_0 is the rest mass. From that we can obtain

$$m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

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[6] See (JAMMER, 1974, p. 87).

In a massless system the value obtained is undetermined, which is the case for photons. However, the relativistic mass (or total energy) of the system can be achieved by the Energy-momentum relation[7] of a physical system, which is obtained from the relativistic equation for moving systems

$$E = \sqrt{m_0^2 c^4 + p^2 c^2}$$

Notice that, if the system is at rest, then the momentum is given by $p = 0$, what leads to

$$E = mc^2$$

On the other hand, if the system is massless, $m = 0$, such as in the case of photons, then

$$E = pc$$

Since $E = mc^2$ then $pc = mc^2$, what leads to $m = \frac{p}{c}$ What gives the relativistic mass in terms of the momentum p. However, notice that the relativistic momentum in some direction x_i, $i \in \mathbb{N}$, and the relativistic momentum in the time direction are given by the following equations:

$$P_{x_i} = \gamma m v_{x_i}$$

$$P_t = \gamma mc$$

Particularly, if $\gamma = 1$, the results are almost the same from Classical Mechanics. Thus, we can say that there is no relativistic mass but just another way to conceive its momentum. The momentum is so important that, if the system is at rest, i. e. $p = o$, then the rest energy E_0 and the total energy E are the same. In this sense, the rest mass and the relativistic mass are the same too.

There are many other aspects from SR, however the results presented here are enough for the purposes of this thesis.

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[7] Dirac used almost the same equation in order to provide the prediction about the antimatter.

C.2 MANY QUANTUM FIELD THEORIES

C.2.1 Classical and quantum fields

There is a general conception that QFT arises from the merge between QM and SR, however, it is clear the crucial role that Classical Field Theory (CFT) has in the theory. CFT is a physical theory that represents many physical phenomena by using the mathematical structure of fields to model quantities linked to those phenomena. Two of the most known structures take into account in CFT are the gravitational field and the electromagnetic field.

Abstractly, fields are mathematical structures modeling physical systems with infinite degrees of freedom (generalized coordinates). Basically, depending on the physical system, a field is conceived as an operator assigning some mathematical feature to points in the space and time structure underlying some given physical theory. If the field operator assigns scalars to the points, then the field is a scalar field. The same goes for vectors, spinors and tensors of all ranks. For instance, the electromagnetic field, which is a combination of both the electric field and the magnetic field (both vector fields), is a physical concept modeled by the mathematical structure of a vector field.

In CFT the four Maxwell's equations provide the basis for many electromagnetic phenomena. The most important for the further development of SR is the demonstration that both the magnetic and the electric field propagate at the constant speed of the light in vacuum. Such discovery opened the doors for the unification of those fields and their mathematical formulation in the form of a tensor field. Nowadays, the electromagnetic field is used to describe the electromagnetic interaction; one of the four fundamental forces of nature and a central feature of QFT.

The mathematical formulation of a field depends on the physical system that one needs to be modeled. In this way, we have here the same situation as in Classical Mechanics where there are different formulations for the same domain. As we have Hamiltonian and Lagrangian formulations for Classical Mechanics, in CFT we also have the same formulations, and the same goes for QFT. For now, let us take the classic case. Here we focus on the Langrangian field theory in CFT.

Basically a Lagrangian in CM can be written as the kinetic energy KE minus the potential energy PE at some point of the space and time.

$$L = KE - PE$$

Such relation gives the energy of the system at any instant, representing the idea that any physical system must conserve energy during a transformation (any kind of transformation).

Any Lagrangian L is based on the action S of the system. It is obtained by integrating the Lagrangian at all instants.

$$S = \int_{t_1}^{t_2} L dx$$

Lagrangian Mechanics deals with discrete physical systems with a finite number of degrees of freedom, while a Lagrangian field has continuous infinite degrees of freedom.

Thus, in the case of CFT (and also in QFT) the Lagrangian L is substituted by the the so-called *density Lagrangian* $\mathcal{L}$. The density Lagrangian is a function that measure the distribution of the L all over the space based on each point of the space. Consequently, the theory is said local: *Locality is the feature modeled by the density Lagrangian.*

Consequently, one way to formulate QFT is by means of the Lagrangian density, or simply Lagrangian. That is why we say that QFT is a local theory. Properly, in QFT one is interested in the Lagrangian density that describes the dynamics of the fields.

C.2.1.1 Quantum fields

For every quantum entity in QFT there is a quantum field and only one field for all entities of the same kind. This occurs because quantum entities have specific features defined by structural properties that define them. There are several types of fields and each one can be used to represent different physical systems.

Primarily, a field is an operator valued distribution, i.e., it is a mathematical apparatus that attributes an operator to each point in determined region of space. Depending on the way an operator acts, it can generate different structures. Below, some of these structures are described according to their general use in QFT.

A *scalar field* is an attribution of values to points of the spacetime structure. In QFT a scalar field is invariant under any Lorentz transformation. The only fundamental particle modeled by a scalar structure is the Higgs Boson. The pion also is described by a similar structure, however, since any pion changes sign (is not invariant) under parity inversion its structure is defined as a *pseudoscalar*.

A *vector field* seems like a scalar field, however, a vector is attributed to each spacetime point. In QFT a vector field represents gauge bosons, i.e., particles with spin 1. Since both scalar and vector fields represent bosons we can say that bosons are represented by *tensor fields*.

A *spinor field* is the mathematical representation of the fermions, i.e., the particles with spin 1/2. A spinor field is required in order to satisfy the Dirac equation, which is a (bi)spinorial equation in which the antimatter is predicted. Basically, it is a field where the Dirac equation for spin and charge have its solutions[8].

A *free field* is a system in which any kind of interaction occurs. Generally, a free field is used to escape from several difficulties encountered in interacting systems. For instance, interacting systems have infinite degrees of freedom, which leads to the problem of take into consideration each degree of freedom in the interactions, however, in free systems we do not need to consider the interaction. What happens is that in a free system the dynamics of each system can be write independently from any other dynamics in a way that each one evolves independently from the others. Nonetheless, QFT has its main significance in the interaction picture. Basically, a free field is represented in terms of a quadratic Lagrangian, what gave us the possibility to obtain (always) a linear equation of motion for the system. This result is important for the free systems. Loosely speaking, linear equations represent the systems moving in straight lines, which means that they are not affecting each other; they are *free*. The *Klein-Gordon equation* is an example of a scalar free field.

Finally, the *interacting field* . An interacting field can be write as a Lagrangian in two parts: a free part and an interacting part.

$$\mathcal{L} = \mathcal{L}_{free} + \mathcal{L}_{int}$$

While the free part represents the free field with no interaction, the second part inserts a perturbative element which disturb/perturb the field at a point. The interaction picture is based in small perturbations around the topological neighborhood of a point in a free field. Such perturbations are made possible by means of power series introduced in the equation above. Such quantities are represented by virtual particles, which have any ontological counterpart.

So, depending on the formulations of the theory and the kind of quantum entity, a field can be structured in many ways and there is no unison concept of a field. After all, there are still formulations of QFT that even relinquish the concept of a field as a fundamental feature of the theory, replacing it by other mathematical structures. One of these formulations will be explored in the following sections: the Algebraic Quantum Field Theory. Anyway, there is always a common feature for all quantum fields: Locality.

After all, there is a unison consent that a quantum field is a means by which one can "[. . .] implement the principle of locality" (HAAG, 2012, p. 105). Understanding how this locality is implemented is very important for the physical and philosophical study of the field concept. Locality is "[t]he essential feature which distinguishes quantum

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[8] In this case the fiber bundle will be a spinor bundle in which the fibers (affine spaces) transform according to the group spin $SO(3)$. For more details (SATTINGER; WEAVER, 2013, p. 17-18).

field theory within the frame of general quantum physics (...)" (HAAG; KASTLER, 1964, p. 848). Properly, QFT arises with the necessity to explain the interaction between particles, which is described as a product of two quantum fields over the same point in the spacetime structure (GOMES, 2015, p. 14). However, the product between two fields under the same point is never well defined (Haag's Theorem), leading to the problem of infinities. Such an issue requires the use of perturbative theories.

Locality is also closely related with causality. As we know, QFT relies on SR, and it conserves several commonalities with that theory, one of them is the same concept of causality. Nonetheless, SR has some specific features that could imply in serious difficulties in QFT. Remember that in SR, causality is defined in terms of spacelike, timelike and lightlike separation. In QFT, features as interaction and commutation relations between observables are based on the causality defined in SR. For instance, two observables O_i and O_j in two different regions of spacetime commute only if there is no relation of causality between them. That occurs when the operators representing them are assigned to two different points, x and y, that are spacelike separated. That is,

$$[O_i x, O_j y] = 0$$

Otherwise, interaction is defined as the field product between field operators on the same point. It is required to be the same point because if it were possible to have interactions between operators acting on points timelike separated, then it would be possible to have interactions between fields at different moments.

Clearly, as we have advanced before, interactions cannot be reduced at spacetime points, and this is a consequence of SR.

> The quantum field φ at a point cannot be an honest observable. Physically this appears evident because a measurement at a point would necessitate infinite energy. The mathematical counterpart is that $\varphi(x)$ is not really an operator in $\mathbb{H}_f$. It is an "operator valued distribution" or, alternatively, it may be defined as a sesquilinear form on some dense domain in $\mathbb{H}_f$. (HAAG, 2012, p. 45)

C.2.1.1.1 Field operators

QFT has its beginning almost at the same time as QM. Actually was Schrödinger himself who first tried to give a relativistic formulation for the wave equation (not a field equation)[9], however, odd results that did not fit in the experimental outcomes lead him to focus on the non-relativistic equation presented before (WEINBERG, 1995, p. 4).

Almost immediately, Klein (1926) and Gordon (1927) deduced independently the same equation, which is now know as *Klein-Gordon equation*. Since this equation is second time-derivative, it is not possible to define the probability amplitude in a non arbitrary way. Only after the second quantization and the introduction of the antiparticles by Pauli is that the equation has begun to provide clear results (GOMES, 2015, p. 32). Nowadays, it is used to described single systems with no charge and no spin, what made this equation almost applicable only in the case of scalar fields such as the Higgs boson.

Another fundamental equation is the *Dirac equation*, which makes part of the first beginning of QFT. This equation presents a modification of the original Klein-Gordon equation relatively to the order of the derivatives, what makes possible to introduce the probability amplitude without the arbitrariness found in the Klein-Gordon formulation. The Dirac equation is a field equation for an electron in an external electromagnetic field, i.e., it can describe massive particles with spin $1/2$, which makes it a spinorial field equation. Actually, analogous to Pauli exclusion principle, where a spinor with two degrees of freedom was included, in the Dirac equation is required a new pair of degrees of freedom, making the Dirac equation a bispinorial equation. Since the equation led to the emergence of an “electron” with the usual electron properties but with negative energies, no one knew what this new spinor meant. Consequently, few years later it was discovered the existence of another kind of particle, now known as positrons, the *antiparticle* of the electron. When the complex Dirac spinor is applied for massless particles we achieve the complex *Weyl equation* as a solution for systems with massless particles and antiparticles. The real equation for the same case is know as the *Majorana equation* which is also a description for systems with spin 1/2. (MAGGIORE, 2005, p. 54-65).

The Dirac equation is a milestone for QFT. It describes the electromagnetic interaction between systems with spin $1/2$. Its predictive success gave rise to the first quantum field theory; *Quantum Electrodynamics* (QED), which is a gauge Abelian theory describing the interaction between electrically charged particles by means of photons. Thereby, the new applications of the electromagnetic in QED led to the *second quantization*. The second quantization, also know as the canonical quantization, is the quantization of field operators in order to represent the old-fashioned quantum particles from QM.

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[9] Notice that *relativistic quantum mechanics* is not the same thing as relativistic QFT. While the former is an old and problematic attempt to describe single-particle systems according to wave equations that are Poincaré invariant, QFT, which is also problematic, deals with systems containing many particles now conceived as covariant fields. QFT can explain odd results of relativistic quantum mechanics such as negative energies in terms of pair creation.

C.2.1.2 Algebraic Quantum Field Theory

For the aims of these thesis we will make a brief presentation of the Algebraic QFT (AQFT). AQFT is an abstraction and generalization of the Hilbert space formulation. Again, we owe such a move to a genius like von Neumann. In a series of papers on ring operators[10] he presents several operator algebras or, so to speak, observable algebras. But, instead his efforts such an attempt has failed. Nowadays, his algebras are called "von Neumann algebras", and have a certain range of application in quantum physics. As a result of his efforts in this area, later Gelfand and Neimark developed the C^*-algebras. Firstly such algebras were developed independently from its original aim, making no reference to observable operators in a Hilbert space. This absence of content make them to be considered as abstract C^*-algebras. On other hand, since each state in a C^* can have a representation in a Hilbert space, it suffices to use what is called "GNS construction" in Representation Theory to define a representation of such states in the Hilbert space.

The most obvious advantage of this approach is the well sound foundation of QFT, however, it comes with a price. Such an approach has almost none practical use. Although a solid formulation of QFT, without a pragmatic counterpart AQFT remains arid as an empirical theory.

The AQFT is an attempt to present QFT in a axiomatic way, or at least in a mathematically precise formulation. Originally proposed by Haag and his collaborators[11], the Haag-Kastler axioms (or Araki-Haag-Kastler axioms) seek to axiomatize how quantum observables can be attached to finite spacetime regions in QFT in order to coordenatize the physical content of the theory.

The main motivation for the AQFT is the axiomatic approach. Furthermore, Haag defends that the basic "[. . .] role of fields is only provide a coordinatization of this net of algebras [. . .]" (HAAG, 2012, p. 105) and even with different formalizations QFT still preserves such structure.

Since the standard formulation for QFT is based on the flat Minkowski space $\mathcal{M}$, the aforementioned regions are take as open sets on this space. Moreover, as $\mathcal{M}$ is a topological manifold, an open region on it is just a neighborhood around some point at $\mathcal{M}$. When we use this open region in order to make a measurement on some observable such an observable gives rise to an algebra directly related with the regions mentioned above, which can be represented as follows:

$$\mathcal{O} \to \mathfrak{A}(\mathcal{O})$$

where $\mathfrak{A}$ is the observable algebra and $\mathcal{O}$ is the open set representing the regions of $\mathcal{M}$.

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[10] See (BLACKADAR, 2006).

[11] See (HAAG, 2012), (HAAG, 2012).

Basically, it represents that to each $\mathcal{O}$ is assigned an operator algebra $\mathcal{A}$. In this case $\mathcal{A}$ is taken to be a $C^{\star} - algebra$. $C^{\star} - algebra$ can be conceived, without an intended representation, as an abstract algebra. On other hand, it can be represented as a concrete $C^{\star} - algebra$. Generally, we can assume that such a representation is the operator algebra for the Hilbert space $\mathcal{H}$. In such case, the operators are bounded operators B, and the set of bounded operators of $\mathcal{H}$ can be written as $\mathcal{B}$. In this case we can replace

$$\mathcal{O} \rightarrow \mathfrak{A}(\mathcal{O})$$

by

$$\mathcal{O} \rightarrow \mathfrak{B}(\mathcal{H})(\mathcal{O})$$

The main idea is that a (causal) net of algebras can be assigned to open regions in Minkowski space. Such algebras are the operator algebras, and thereby they are strictly related to the symmetries of the theory.

Basically, AQFT can be summarized in few axioms (postulates).

(i) (locality) to every open region $\mathcal{O}$ in Minkowski space there is an associated $\mathfrak{A}$:

$$\mathcal{O} \rightarrow \mathfrak{A}(\mathcal{O})$$

(ii) (isotony) for every inclusion of open regions $\mathcal{O} \rightarrow \mathcal{O}$ there is a inclusion $\mathfrak{A} \rightarrow \mathfrak{A}$.

(iii) (microcausality) for whenever $\mathcal{O}_i, \mathcal{O}_j \subset \mathcal{O} \subset \mathcal{M}$, if $\mathcal{O}_i$ and $\mathcal{O}_j$ are spacelike separated, then the elements of the operator algebras associated to each of them commute.

The isotony allows us to define that if an observable A "(...) is measurable in a region O_1 it is *a fortiori* measurable in any region O_2 containing O_1." (HALVORSON; MÜGER, 2006, p. 14)

Thus, the microcausality states that superluminal signaling is forbidden. This is represented in AQFT when two observable algebras, $A(O_1)$ and $A(O_2)$, are spacelike separated. If it is the case then they mutually commute (outside the lightcone[12]. This is called "local commutativity" (HAAG; KASTLER, 1964, p. 849).

Haag states that the superselection sectors of a quantum system correspond to unitarily inequivalent representations of the C^{*}. Thus an interesting advantage in using the algebraic approach is that perhaps this approach could trow some light on

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[12] See (HALVORSON; MÜGER, 2006, p. 25), (HAAG, 2012, p. 44).

the relations between QM and QFT. As we know, there is no clear relation between operators in QM and quantum fields in QFT. However, in some sense, the link between QM and QFT is subjected to the superselection rules; and both QM and QFT have the same feet on the C^*. Consequently, both conserve several similarities on this ground[13].

Since the net algebras are assigned only to regions of space (open regions), AQFT has several limitations concerning observable that depends on infinite regions.

> First, we consider the algebras $\mathfrak{A}(\mathcal{O})$ as (abstract) C^*-algebras, not as operator on a Hilbert space. Secondly, we exclude from the list of “all” observables those quantities which refer to infinitely extended regions. Thus the total energy, total charge, etc., are considered as unobservables. (HAAG; KASTLER, 1964, p. 849).

Thus, AQFT deals just with local observables and does not take into account global observables (e.g. total charge)[14]. Consequently, the empirical limitations of the theory becomes clear.

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[13] See (KUHLMANN, 2010, p. 46).

[14] About external symmetries and global observables see (KUHLMANN, 2010, p. 24-26).