Introduction
Progressive Steps toward a Unified Conception of Individuality across the Sciences

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In Guay, A. & Pradeu, T. (eds.) *Individuals Across the Sciences.* New York : Oxford University Press, 2015, ISBN 978-0-19-938251-4, p. 1-21.

1.1 Connecting Metaphysics and the Sciences

How to define and identify individuals has been a recurring issue throughout the history of philosophy. It was, for example, pointedly studied by Aristotle in his *Metaphysics* and *Categories*, by Locke in his *Essay*, and by Leibniz in his *New Essays*. Most contemporary philosophers consider the problem of individuality from a general, metaphysical, point of view, as is the case, in particular, of Peter Strawson in his landmark book *Individuals: An Essay in Descriptive Metaphysics* (Strawson 1959) and David Wiggins in *Sameness and Substance* (1980) and subsequently in *Sameness and Substance Renewed* (2001). In sharp contrast, the preferred approach in philosophy of science has been to define, in a very focused and circumscribed way, the ontological status of certain individuals, most often within a specific scientific domain, typically physics (e.g., Saunders 2006, French and Krause 2006, Ladyman and Ross 2007, Muller and Seevinck 2009, Caulton and Butterfield 2012, Dorato and Morganti 2013, Morganti 2013, French 2014), or biology (e.g., Hull 1978, 1980, 1992, Buss 1987, Maynard-Smith and Szathmáry 1995, Michod 1999, Wilson 1999, Gould 2002, Wilson 2005, Dupré and O'Malley 2007, Godfrey- Smith 2009, Clarke 2010, Pradeu 2012, Bouchard and Huneman 2013, Wilson and Barker 2013). Today, many consider that the approach used in philosophy of science has been much more precise and globally much more fruitful than the purely metaphysical approach, often criticized for being excessively general and at odds with "real" science (this view is defended, in particular, in Redhead 1995, Maudlin 2007, Ladyman and Ross 2007, Ross, Ladyman, and Kincaid 2013; see also French 2014). It seems crucial to spell out in detail this conflict between the highly general approaches favored by metaphysicians and the much more focused approaches favored by philosophers of science, and to determine to what extent this conflict could be overcome.

This volume stemmed from two observations, which can be seen as two reactions to the conflicting landscape just described. First, the recent developments in the notion of individuals in physics or in biology, fascinating as they are, have remained in most cases "regional," in the sense that very few transversal reflections, offering a meticulous comparison between various conceptions of individuality and/or various scientific individuation criteria across different sciences, have been done (a recent and stimulating exception is French 2014). In an attempt to at least partially fill in this gap, the present volume offers a confrontation of philosophers of physics and philosophers of biology on their definitions of individuation criteria. Several chapters of the volume are intrinsically interdisciplinary, while others rather belong to either philosophy of physics or philosophy of biology but at the same time take into account lessons that can be learnt from the other field. Second, the advantage of the regionalism that characterizes scientific approaches to individuality is, naturally, that it is well focused and precise, insofar as it isolates a relatively small field of study, but the difficulty is that too often it lacks ambition compared to the aim of metaphysical approaches, namely to uncover the general conditions for individuating any object (e.g., Strawson 1959, Wiggins 2001, Macdonald 2005, Lowe 1989, 2006). To address this difficulty, the present volume attempts to articulate the perspective of general metaphysics with that of philosophy of physics and philosophy of biology on individuals. This confrontation between metaphysics and science should not be a "battlefield" (to use Kant's famous image), in which each side would misunderstand the basic methodology of the other; instead, progress will be made only thanks to the work of metaphysicians informed by today's sciences, and philosophers of science who keep in mind metaphysics' goal to develop a unifying and operative notion of the individual. The present volume, in other words, aims at clarifying and overcoming the difficulties that hold back the construction of a general conception of the individual that would be adequate for both physics and biology, and perhaps beyond.

The kind of convergence between metaphysics and science advocated here can be partly related to "metaphysics of science," a label that has recently aroused much enthusiasm in the philosophical community (e.g., Mumford and Tugby 2013). Logical empiricists famously looked at metaphysics with suspicion, and even suggested that most metaphysical statements were meaningless (because they were neither analytic nor synthetic) (see, in particular, Carnap 1935). The critique of logical empiricism in the second half of the twentieth century led, among other things, to a resurgence of metaphysics in Anglophone philosophy, and to the view that there was perhaps no strict and clear-cut boundary between metaphysics and science. The 2000s witnessed a burst in "metaphysics of science" with, notably, fascinating work about laws, causation, dispositions, natural properties, and natural kinds (see, e.g., Kistler 2006, Bird 2007, Chakravartty 2007, and, for an overview, Mumford and Tugby, 2013). We believe that metaphysics of science as it has been done in the last 15 years or so is right in its most fundamental project, which is both very ambitious and legitimate: *aiming at building a general worldview on the basis of several sciences* and, if possible, a worldview that would hold for all the sciences (for an explicit claim that such is the fundamental goal of metaphysics of science see, again, Mumford and Tugby 2013: 6). The problem is that some claims made in metaphysics of science are, according at least to many practitioners of science and/or to philosophers who are very close to science itself, excessively general and far from "real" science; it is certainly not clear, for instance, that all sciences offer laws, pace a majority of metaphysicians of science (it is likely, in particular, that a majority of biologists and philosophers of biology would reject the idea that there are biological "laws").

In contrast with some (though certainly not all) "metaphysicians of science," when we talk about the articulation of metaphysics and science, we have in mind a metaphysics that is well informed by actual and present-day science, in a precise and therefore limited way: metaphysicians interested in building a scientific metaphysics must put a lot of effort in knowing in detail one scientific field, without presupposing the existence of structural features of an allegedly general way of doing science that would hold for all the sciences (Maudlin 2007, Ladyman and Ross 2007, Ross, Ladyman, and Kincaid 2013, French 2014). This investment into science itself is necessary for the construction of a solid scientific metaphysics, but it is by no means sufficient: indeed, the sciences do not by themselves offer a pertinent and well-articulated metaphysics, which is to say that metaphysics cannot directly be read off the sciences, as argued convincingly by Morganti (2013). Philosophers interested in science and scientists interested in reflecting on metaphysics need to patiently *build* this scientific metaphysics, using scientific theories and practices, as well as metaphysical concepts and approaches, as their main tools. French and McKenzie (2012) have suggested that metaphysics should be used as a "toolbox" for the construction of a pertinent and scientifically sound worldview; what we suggest here is that both the sciences and general metaphysics should be used as “toolboxes” for the construction of an adequate scientific metaphysics.

In accordance, therefore, with the recent “metaphysics of science” trend, we think that generality is a very important aim for science and metaphysics. But we are also convinced that *general claims of a science-based metaphysics have to be patiently constructed*, rather than being assumed in the first place. For instance, because so many physicists and philosophers of physics have cast doubt on the idea of causality, their arguments have to be carefully examined before making any claim about the supposedly self-evident view that all sciences need the concept of causality and, even more tentatively, a concept of causality that would be common to all scientific domains. The strategy followed in this volume is then more modest and more progressive than that of many proponents of recent “metaphysics of science”: instead of offering from the start a concept of an individual that would hold for all the sciences, we try to determine *whether or not such a concept can emerge from the actual confrontation of two different scientific fields*, namely physics and biology. In our view, this modest strategy is in fact the only way to reach the aforementioned ambitious aim, that is, the construction of a general and scientifically informed worldview. What we need to do, then, is to explore the resemblances and differences between the physical and the biological senses of the term “individual.” Let us now justify this choice of limiting our inquiry to physics and biology, and then explain how the concept of individual is used in physics and in biology, respectively.

1.2 The Many Faces of Individuality in the Sciences

The notion of individuality is used extensively, and differently, in many sciences. This includes, naturally, physics and biology, as this volume will show in detail. But the notion of individuality also plays a critical role, for instance, in economics (e.g., Davis 2010), sociology (e.g., Elias 1991), anthropology (e.g., Dumont 1986), and the social sciences in general (Rosenberg 1988), as well as in chemistry—where a major aim is to understand how individual entities *aggregate* (for an overview, see Weisberg, Needham, and Hendry 2011). Despite this rich diversity, we have decided, in this volume, to focus almost exclusively on the physical and the biological sciences. At least two reasons explain this choice.

First, as this volume will make clear, the articulation of the physical and the biological discourses on individuality is already extremely complex; by no means would we want to suggest by this choice that the physical and the biological approaches are the *most* complex, or the *most* interesting; we are simply convinced that, to address an extremely complex problem, one has to start somewhere, and if possible at a place where it seems clear that progress is likely to be made.

Second, the incomparably long and rich traditions in philosophy of physics and philosophy of biology have given rise to many debates about the notion of individuality in these fields, and it seemed a reasonable strategy to start with, and build on, these previous debates. We hope that the present volume will stimulate others to explore other scientific domains, and that future work will indeed address the problem of how to understand individuality in those scientific fields and, even more importantly, of how to articulate the different conceptions of individuality conveyed by these various fields. Opening up some possibilities, this volume, here and there, touches upon other scientific fields (Paternotte, for instance, uses the evolutionary notion of a collective entity to shed light on how the social sciences conceptualize what a collective being is and how joint action should be understood).

So, what is an individual, and how is this notion used in the sciences? Though there is much disagreement among metaphysicians about how to define an individual, most would probably agree that an individual is, minimally, an entity that can be singled out and counted, possesses acceptably clear-cut boundaries, and shows some identity through time ("persistence"). Every aspect of this apparently simple definition deserves to be analyzed—and perhaps put into question, as will appear clearly in the contributions of Chauvier and Lowe, in particular. In addition, one must address the question of whether or not such an understanding of what an individual is could be applicable and useful in today's sciences. In what follows, we tentatively lay the foundations of possible ways to define individuals in physics and in biology. Needless to say, the different chapters of this volume will explore in much more detail what physics and biology have to say (or don't have to say) about the notion of an individual.

1.3 Individuality in Biology

Not only have philosophers traditionally been interested in determining what a biological individual is, but many of them (e.g., Aristotle and Locke) also have used biological individuals as *paradigmatic* individuals, that is, as models to better understand what an individual in general is (see Hull 1978, 1992). One important difficulty, though, is that the individuation of biological entities is much more complex and surprising than might be expected by those having in mind familiar and relatively "big" animals such as mammals (Hull 1992), and therefore it is perhaps not entirely certain that biological entities should still be viewed as models for the understanding of individuals more generally. In the last decades, both biologists and philosophers of biology have suggested finding biological criteria (as opposed to common-sense criteria, which lead to what can be called *phenomenal individuation*) for the individuation of biological entities, and this has led to one of the most active debates within philosophy of biology (e.g., Hull 1978, 1980, 1992, Buss 1987, Maynard-Smith and Szathmáry 1995, Michod 1999, Wilson 1999, Gould 2002, Wilson 2005, Okasha 2006, Dupré and O'Malley 2007, 2009, Godfrey-Smith 2009, Clarke 2010, Pradeu 2012, Bouchard and Huneman 2013, Wilson and Barker 2013). In fact, many individuality criteria can be used to delineate living things, including physiological, embryological, genetic, evolutionary, immunological, and neurological criteria. For the sake of simplicity, two main sets of approaches can be distinguished among individuations based on the biological sciences:

1. *Physiological individuation*: this approach grounds biological individuality mainly in the numerous biological fields that are interested in the explanation of actual working of present-day living entities (those fields include, for instance, much of molecular and cellular biology, neurobiology, immunology, etc.). Very often (but certainly not always), the main focus in this approach is the organism, seen as a strongly cohesive and unified metabolic entity, with mutually dependent components (e.g., Perelman 2000, Pradeu 2010).
2. *Evolutionary individuation*: proponents of this approach consider, behind Hull (1978, 1992), that the theory of evolution by natural selection is our best tool to say what a biological individual is, because evolution is in the background of all biological processes, and because the theory of evolution by natural selection is arguably the most powerful and comprehensive theory of biology. (On this distinction between physiological and evolutionary individuation, see Pradeu 2012; see also Wilson and Barker 2013.)

Recent debates over individuality within the domain of philosophy of biology have been dominated by evolutionary approaches to individuality. Important contributions have concerned biological individuals as units of selection (e.g., Hull 1978, 1980, 1992, Gould 2002), as results of a "transition in individuality" (for instance from unicellularity to multicellularity: e.g., Buss 1987, Maynard-Smith and Szathmáry 1995, Michod 1999, Okasha 2006), or as "Darwinian individuals," that is, members of a "Darwinian population," itself defined as a set of entities characterized by variation, fitness differences, and heritability (Godfrey-Smith 2009, 2013). Other contributions have paid more attention to physiological individuation (e.g., Sober 1991, Mossio and Moreno 2010, Pradeu 2010, 2012; see also Dupré and O'Malley 2009, Godfrey-Smith 2013), but they have tended to be less influential than evolution-based approaches.

Overall, most philosophers of biology have considered that biological
Individuality

- Cannot be grounded in our everyday notion of what an individual is (e.g., Hull 1992)
- Has to be grounded in biological *theories* (an idea that is reminiscent of Quine (1948, 1960), but that can naturally be questioned, as does Chen in this volume, for instance)
- Is dependent on the question being asked, and, often, on the domain of study
- Can appear at several levels (it is a "hierarchical" or "multilevel" perspective on individuality: e.g., Hull 1980, Gould and Lloyd 1999, Gould 2002)
- Comes in degrees (e.g., Santelices 1999, Godfrey-Smith 2009)

1.4 Individuality in Physics

In physics, individuals are not an obvious given. There is no straightforward equivalent of the organism, for instance. After the rise of relativistic and quantum physics, the belief that the world is populated by objects with a sufficiently strong identity to be called "individuals" cannot be admitted without demonstration. This question has led to a real debate in physics and philosophy of physics, a debate that has focused on exactly the question of whether or not it was still possible to talk about physical "individuals." During this debate, new distinctions and definitions were proposed, and new approaches were explored. This brought the discussion farther and farther from its original sources, which lay in the metaphysical and biological traditions. Indeed, one could even wonder if the current discussion on physical individuals is about individuals at all. For example, the kind of individuals discussed in the quantum context would probably not be considered as "real individuals" by many metaphysicians. But this conclusion, of course, is disputable, in view of the suggestion made above that the a priori conceptions often favored by metaphysicians should not necessarily be the final word in metaphysics.

In the following, we will mention only a few of the avenues recently discussed in the literature. In most researches, a basic distinction is made between problems relating to the synchronic and the diachronic identity of individuals. The belief that it is legitimate to separate these classes is often founded on the belief that intemporal individuals, this is, individuals that do not persist, could exist. And since many, if not most, metaphysical conceptions of an individual include, as a necessary condition, persistence in time, it seems that philosophers of physics became interested in a new metaphysical concept, something different from the concept of individual as such.

Importantly, it is not a general reflection about the temporal dependence of individuals that originally motivated philosophers of physics to explore the possibility of intemporal individuals, but mainly permutation arguments involving possibilities equivalence, in other words an equivalence between models potentially describing different worlds. For example, if we rearrange space-time points in such a way that no empirical consequence follows, do we face a new physical situation or just another description of the same situation? The latter possibility makes it difficult to sustain that space-time points are individuals, while the former leaves this possibility open. But of course space-time points do not persist. If they are individuals, they are not temporally extended. One could argue that the individuality of space-time points explains why the situations after permutation are distinct. In this position, their individuality involves some kind of modal aspect that guarantees transworld identity. Many similar permutation arguments could be found in the literature, for example, about identical particles in quantum and classical physics (Castellani 1998, Brading and Castellani 2003).

It seems legitimate to discuss the possibility that individuals exist only at a certain time, an idea that has provided incentives for the bundle theory of physical individuality. In the context of this theory, an individual is defined by its properties at a certain time. Usually, a contrapositive version of the principle of identity of indiscernibles is invoked: no two distinct individuals share all the same individuating properties. "What is an acceptable individuating property?" is a difficult question. Should we include relational properties and/or space-time locations? If we do, the ontological status of these properties has to be clarified (French and Krause 2006), but this task is far from being simple (Earman 1989, Stachel 2002, 2004). An empiricist and more modest strategy is also possible (Saunders 2006). Instead of metaphysical individuating properties, this strategy consists in promoting the notions of absolute and weak discernibility as fundamental identity criteria (see Quine 1976, and Saunders's chapter in this volume). This makes the individuating properties more clearly dependent on our linguistic framework.

The bundle theory is not the only philosophical approach framing the debate. The particular kind of empiricist motivation (only properties indexed by space-time points are metaphysically acceptable), implicit to the bundle theory, is not shared by all. Moreover, one could believe that temporal extension is required to be an individual. Fortunately, other options are available. One could expand the bundle theory to include properties at different space-time locations, for example using genidentitical relations among events to define individuals (see Reichenbach 1956, as well as Guay and Pradeu's chapter in this volume). This approach is potentially efficient to sustain a strong diachronic identity criterion but seems less useful if ephemeral individuals are considered. Moreover, in this approach, quantum particles are generally considered as non-individuals. This position is the "received view" in physics' community. Within physics, the discussion generally stops there. But philosophers, for their part, ask for a more precise characterization of the non-individuality that is typically the result in quantum physics. Quantum particles are countable. They also are weakly discernable. So if they are not individuals, what are they?

In reaction to the above view, a more metaphysically inclined position would be to consider individuality as something beyond and above any individual's properties. Many variants are defendable, from haecceitism to bare individuals to systemic properties (Adams 1979, Lewis 1986, Morganti 2013). The absence of empirical access to the individuating features could be seen as a real problem for these positions. But if they manage to shed some light on certain ontological puzzles, like the origin of quantum statistics, they could be taken as viable metaphysical options (Morganti 2009, 2013).

Overall, current philosophers of physics consider physical individuality as at least one of the following:

- Nonexistent
- A kind of property profile
- A kind of space-time process
- Something primitive, beyond any properties

1.5 Building Bridges

Even though spelling out in detail what the notion of an individual means in physics and in biology is interesting by itself, the most stimulating task from the point of view defended here is to determine how to compare the conceptions of individuality found in physics and in biology, and if possible to articulate them into a more integrative framework. Yet this is far from being an easy task. At first sight, at least, physics and biology appear to differ very significantly in the way they conceptualize individuals and address the problem of individual identity through time (a more detailed analysis of these differences can be found in the chapter of Guay and Pradeu in this volume):

(1) Parts-whole questions seem crucial in biology. This probably has to do with the fact that most, if not all, biological entities appear to be constituted of smaller biological entities (as, for example, when one asks to what extent the cells constituting a multicellular organism are themselves "individuals"). Parts-whole questions play a less important role in physics, where many discussions concern particles situated at a fundamental level, and/or "entities" that cannot be easily individuated (as an electromagnetic field, for instance).

(2) A crucial issue in physics is to determine how to distinguish one particle from several other, supposedly "identical," particles. In contrast, in biology, even individuals that are said to be "identical" express, most of the time, some significant differences and, at the very least, can usually be distinguished one from the other from a spatial point of view.

(3) In discussions about synchronic identity in physics, the principle of indiscernibles is critical. The same is not true in biology: in everyday practice, at least, biologists often say that two living things are "identical" even when they do not share all their properties, in particular their position in space. A nice example is that of "clones," which are often described as "identical"—even though many data suggest that clones always express differences. (Interestingly, the combination of (2) and (3) suggests that discernibility is easier but at the same time considered as less crucial in biology than in physics.)

(4) Discussions over structuralism are extremely important in physics. Many physicists aim at determining what remains invariant under transformations. By contrast, structuralism plays a limited role in biology, if any (exceptions include French 2011, 2014, as well as French's and Ladyman's chapters in this volume).

But do these differences between physics and biology undermine the project of articulating these two fields in the hope of building a more unified perspective on individuality? Several contributions to this volume suggest that the answer to this question is negative; in other words, they show that a fruitful dialogue can be established between physics and biology on the individuality issue. In some cases, they defend a general worldview initially grounded in physics, and then show how it can be extended to biology (e.g., French explains how ontic structural realism and an eliminative attitude toward individual objects can be applied not only to physics but also to biology); in other cases, they analyze two fundamental examples, one taken from physics and the other from biology, to defend a general approach to scientific objects (for instance, Chen uses the case of Bose-Einstein condensates in physics and that of genetic engineering in biology to defend the idea that scientific individuation should be grounded in experimental *practice* rather than in scientific theories); in still other cases, they make a point that clearly belongs to one scientific field, but show nonetheless how it can be related to a theory or a view belonging to the other field (for instance, Fagan defends an "uncertainty principle" with regard to the definition of stem cells, and then, building on Saunders and others, she explores the analogy between this principle and the famous uncertainty principle of quantum mechanics); finally, some chapters try to demonstrate that a common principle of individuation can be applied to both physical and biological cases, and that each illuminates the other (for instance, Guay and Pradeu argue that the so-called genidentity view sheds light on the individuation through time of both physical and biological entities).

But the network of disciplinary interactions to be found in this volume is even more complex than that, as it includes, in addition to a dialogue between physics and biology, a dialogue between metaphysics and those sciences. Indeed, several chapters show how metaphysical, physical, and biological views on individuality have been interacting in intricate and fascinating ways. Our metaphysical notions often come from "folk science"— in particular, as has been emphasized above, from "folk biology" (e.g., Aristotle, in his Categories, explains his metaphysical concept of primary substance by giving the example of "an individual horse"). In turn, science often cast doubt on our intuitive concepts of what an individual is, and this can probably lead to a transformation of these intuitive concepts, which are, therefore, probably much less eternal, immutable, and "a priori" than many metaphysicians have thought (a nice example of this complex interplay is the way the notion of an immunological individual has been inspired by the "self" concept found in the psychological and social sciences, and then has in turn modified our conception of what it means to be a human "self" in present-day societies: see, e.g., Tauber 1991, Cohen 2009). Several chapters of this volume, among others those of Morganti, Saunders, Haber, and Ereshefsky and Pedroso, demonstrate that general metaphysics and the sciences can and should talk to each other, and that much gain is to be expected from this dialogue.

1.6 Book Structure

Laying aside chapter 1 (which is the present introduction), this volume is composed of 17 chapters, organized into three parts. The first part concerns metaphysical and logical foundations to individuality. The second part explores puzzles about individuals in a specific science, most often biology or physics. Finally, the third part focuses on transversal problems, that is, problems that arise at the interface between physics and biology, or at the interface between metaphysics on the one hand, and biology and/ or physics on the other hand.

1.6.1 Part I: Metaphysical and Logical Foundations to Individuality

Part I provides a general and wide-ranging perspective about the notion of individual, as the contributions gathered in this part explore what an individual is from a metaphysical and logical point of view. Therefore, they are situated at the most fundamental, and potentially most unifying, level. One possibility would be to consider that approaches of this kind define every individual, whatever the domain of inquiry; in that case, they would impose delimitations and restrictions on how the sciences, and in particular physics and biology, may define the notion of individual. Alternatively, one could consider that these approaches are to be built, and constantly modified, on the basis of what current sciences say (and future sciences will say)—in which case their objective would be to reflect on current sciences in order to offer an as good as possible (though always precarious) view on what an individual in general is.

The aim of the chapters gathered in this part, therefore, is to constitute a wide and unifying picture of individuality, one that should be used as a foundation for the development of more specific conceptions of individuality, as, for examples, those that different experimental sciences could offer. However, it will be apparent in Parts II and III that many philosophers of experimental sciences do not in fact use the logical and metaphysical discourses as foundations for the ontological investigation of physics and biology: these discourses are considered top-down approaches, and therefore concurrent to the bottom-up methodology characteristic of philosophy of science.

Chapter 2, written by Stéphane Chauvier, can be seen as a conceptual basis for the rest of the volume. Chauvier distinguishes two concepts of an individual: the *logical-cognitive* concept of a discrete particular, and the *ontological* concept, which applies more stringently to entities that exhibit ontological autonomy, formal unity, and qualitative singularity. He then shows that ontological individuality matters, in two senses. First, not every particular object of thought, even of scientific thought, is a real individual, since what is individuated by us, by our way of conceptually dividing the world, is not necessarily individuated *in itself*. Second, not every real being is a real individual or is an individual to the same degree. Thus, according to Chauvier, the ontological concept of an individual can be used as a basis for a complete division of real beings, by distinguishing *individuals* and *non-individuals* (aggregates), but also by distinguishing various *degrees* of individuality and aggregativity.

In chapter 3, Jonathan Lowe (who so sadly died on January 5, 2014, only a few weeks after having submitted his contribution for the present volume) argues for the possibility of entities that are not individuals. Having claimed that an entity x is an *individual* just in case (1) x determinately counts as one entity, and (2) x has a determinate *identity*, Lowe shows that it is both logically and metaphysically possible for there to be *non*-individuals, that is, entities which fail to satisfy either clause (1) or clause (2)—or both. Lowe then explores the potential application of this distinction between *individuals* and *non-individuals* within and across the sciences, in a spirit of fruitful cooperation (rather than mutual hostility) between analytic metaphysics and theoretical science.

In chapter 4, Krause and Arenhart argue for the importance of logical and formal considerations in any discussion about individuality. They start with an intuitive definition of an individual (as a unity, having identity and being such that it is possible at least in principle to discern it from any other individual). But they then show that, when we leave the intuitive realm and attempt a logical analysis, we find a cluster of problems that are difficult to overcome within standard logico-mathematical apparatuses. They question the intuitive notion of an individual in view of recent discussions that arise in quantum theory, and they push the discussion to a “logical” view. They characterize individuals by means of invariance by automorphisms and, finally, they propose a metaphysics where the notion of identity is replaced, for some objects, by a weaker notion of indiscernibility.

1.6.2 Part II: Puzzles about Individuals in Biology and Physics

In Part II, each chapter investigates a particular conception or a particular puzzle about the application of the individuality concept to biology or physics. Even though each chapter is strongly focused on a specific science, many of them draw parallels between different sciences, or between metaphysics and science.

Let us first discuss the chapters grounded in biology. As emphasized above, Peter Godfrey-Smith, in recent publications, has suggested the concept of a "Darwinian individual," understood as a member of a "Darwinian population" (Godfrey-Smith 2009, 2013). In chapter 5, entitled "Individuality and Life Cycles," Godfrey-Smith shows that many recent discussions over biological individuality have focused on *spatial* aspects of individuality. But, he claims, *temporal* aspects of individuality are as important as spatial aspects. Many familiar organisms are "reproducing continuants": they come into being, persist, and then die. Yet some living entities put pressure on this familiar view, and on the traditional conception of heredity to which it is associated. Godfrey-Smith analyses several cases of complex life cycles, in particular some featuring "alternation of generations" (a process in which entities of a kind A make entities of a kind B, which in turn make entities of a kind A—like ferns, for instance), and eventually offers a renewed and extended conception of reproduction.

In chapter 6, Marc Ereshefsky and Makmiller Pedroso use the example of biofilms to examine Hull's and Godfrey-Smith's accounts of biological individuality and to explore the nature of individuality more generally. According to Ereshefsky and Pedroso, the case of biofilms shows that Godfrey-Smith's account of biological individuality is too restrictive, while Hull's interactor account is appropriately inclusive. The chapter then augments Hull's account in three ways. First, Hull's notion of interactor is embedded in a general theory of individuality that applies to individuals both in and outside of biology. Second, the sort of interaction required of the parts of an individual is explored and elaborated. Third, Hull's commitment to replicator theory is dropped and Griesemer's account of reproducers is adopted.

In chapter 7, Melinda Fagan considers the biological individuality of stem cells (i.e., undifferentiated cells that self-renew and give rise to differentiated cells). She argues that stem cells are not biological individuals in the same way as cells of multicellular organisms, but at the same time she claims that some stem cells at least are biological individuals in the way of *multicellular organisms*. Her approach sheds light on central concepts and practices of stem cell biology, as well as the relation between cell and organismal individuality. The stem cell case also exhibits an unexpected parallel with physics, specifically Bohr's view of complementarity.

In chapter 8, Cédric Paternotte develops the analogy between a collective engaged in a joint action and biological individuals. He shows first that there exist many definitions of human joint action, or of what makes a group similar to an individual, but these definitions do not agree and are not directly reducible to each other. Paternotte argues that these definitions should at least meet an efficiency constraint: any account of joint action has to justify how it reliably leads agents to cooperation. The avenue suggested by Paternotte consists in exploring the analogy between definitions of joint action and of biological individuality, because the main components for biological individuality have been identified and their relations are much better understood than those between the components of human joint action. Paternotte concludes that we can import some insights of the biological literature to define what a joint action is, and when a group can and should be considered as an individual.

Let us now move to the chapters that focus mainly on physics. In chapter 9, Simon Saunders shows that, at a fundamental level, the world is built up from quantum fields, and then asks how we pass from this to the objects of the special sciences. In his view, there are two critical transitions: one is from indistinguishable to distinguishable things that persist over time—

individuals—and the other is the transition from quantum to classical or semi-classical systems. He argues that the two are interlinked, and that the key method is to pass from a description in terms of particles whose only intrinsic attributes are mass, charge, and spin, to one in terms of individuals whose intrinsic attributes include stable dynamical properties—among them, spatial location, as provided by state-collapse, whether effective (as in many-worlds and pilot-wave theory) or fundamental. Saunders adds that there is also a connection with ontological relativity (or Putnam's paradox): the same method, applied to model theory, leads from permutable particulars that have no intrinsic attributes to distinguishable bundles of properties.

In chapter 10, James Ladyman discusses the debate about individuality, quantum particles, and the principle of the identity of indiscernibles. He argues that if the definability of identity is at stake, then the cut does not come between individuals and non-individuals as usually defined, but rather between weakly discernible and completely indiscernible entities. If what is at stake is the principle that identity must be grounded in qualitative properties, even things that are absolutely discernible, in the sense of their being at least one property that one has and not the other, may only be so in virtue of relational properties. If individuality can be grounded in non-qualitative features of the world, or if a logically thin notion of individuality is adopted, then quantum particles may be individuals after all. Ladyman concludes that the metaphysically significant notion of individuality apt for quantum particles is that of "real pattern."

In chapter 11, entitled "Minimal Structural Essentialism: Why Physics Doesn't Care Which is Which," David Glick argues for a trans-structural identity. He starts by noticing that the ways in which space-time points and elementary particles are modeled share a curious feature: neither seems to specify which basic object has which properties. The aim of Glick's chapter is to explain this. After reviewing several proposals, he argues that objects occupy their place in a given relational structure essentially. This view, called "Minimal Structural Essentialism," provides a metaphysical grounding for the physical equivalence of models related by permutation. According to this view, space-time points and elemental particles turn out to be individuals, albeit of a rather different sort than has traditionally been considered.

In chapter 12, Paavo Pylkkänen, Basil J. Hiley, and Ilkka Pättiniemi start with Ladyman and Ross's view that quantum objects are not individuals (or are at most weakly discernible individuals), which constitute the basis of Ladyman and Ross's defense of "ontic structural realism," according to which relational structures are primary to things. In response, Pylkkänen et al. draw attention to a version of quantum theory, namely the Bohm theory, according to which particles do have definite trajectories at all times. According to them, this view suggests that quantum particles are individuals after all, with position being the property in virtue of which particles are always different from one another. However, Pylkkänen et al. also admit that the individuals of the Bohm theory are very different from those of classical physics, and they resort to structuralist considerations to better understand their nature.

Finally, Christina Conroy, in chapter 13, goes a step further in proposing that, even if we had a robust concept of physical individual at a certain time, this individuality would be weakened if we took into account Everett's interpretation of quantum mechanics, for which the world is constantly branching. She shows that, when considering persons, one must consider the criteria for re-identifying a person over time. She then explains that in the context of the metaphysical picture implied by Everettian quantum mechanics—one that includes some type of branching structure to the world—problems of diachronic identity arise. This is in fact a

Ship of Theseus-type problem. Conroy argues that an answer to the question "With whom will I be identical post-branching?" can be found in analogy with a solution proposed by Derek Parfit in his "Personal Identity" (1971). She proposes that we use a notion of branch-relative identity instead of the traditional equivalence relation of identity to solve this problem. This chapter thus concludes rich discussions, both in biology and in physics, on how individuals can be conceived.

1.6.3 Part III: Beyond Disciplinary Borders

The third part of the book is composed of chapters that explicitly transcend disciplinary borders, be they the borders between metaphysics and science, or those between physics and biology.

In chapter 14, Matteo Morganti argues for a pluralistic approach to the concept of individual. First, he looks at the debate about identity and individuality in non-relativistic quantum mechanics and offers a defense of the view according to which identity facts are primitive in that domain. Second, his chapter constitutes a contribution to the clarification of the relationship between science and metaphysics, in particular with respect to what a proper "naturalistic" methodology should and should not be taken to entail as far as the theme of individuality is concerned. His guiding idea is that taking identity and individuality facts as basic is not necessarily in conflict with naturalism. The overall picture that emerges from Morganti's chapter is that of a "pluralistic" approach, whereby different scientific domains and theories are likely to allow, and in fact to ask for, different forms of individuality.

Matt Haber, in chapter 15, raises the issue of the relationship between metaphysical mereology and biological debates over the idea that species would be individuals. Haber starts with Michael Ghiselin and David Hull's "individuality thesis," which famously states that biological species are individuals. Philosophers, Haber shows, have often interpreted this thesis in a mereological way, species being seen as mereological sums. Yet Haber argues that this is a mistake, since biological part/whole relations often violate the axioms of mereology. According to Haber, conflating these projects confuses the central issues at stake in both, and makes the job of evaluating them extremely difficult. His clarification of this issue helps identify the genuine metaphysical implications of the individuality thesis, which serves as an exemplar of scientifically informed metaphysics.

In chapter 16, Guay and Pradeu offer a defense of the "genidentity" thesis, first put forward by Kurt Lewin (1922), and then by Hans Reichenbach (1956). They show that the original notion of genidentity was often imprecise and not easily applicable to real scientific cases. In their view, however, a renewed notion of genidentity can be suggested, and this notion can shed important light on physical and biological cases. Guay and Pradeu draw lessons from physical examples of the genidentity view, and apply them to biological cases, in particular cases discussed by David Hull—one of the very few philosophers of science having supported explicitly, in recent times, genidentity. In conclusion, they suggest that genidentity could be an important argument in defense of a processual worldview.

In chapter 17, Ruey-Lin Chen discusses the *experimental realization of individuality*—the production of individuals posited by scientific theories. Experimental realization refers to the processes by which scientists produce new phenomena, properties, entities, or individuals by means of experimental techniques and instruments. On this basis, Chen addresses two main questions: (1) Is there a conception of individuality in and across experimental sciences? (2)

Under what conditions can scientists be said to realize the individuality of an object? By examining the creation of Bose-Einstein condensates in experimental physics and the modification of genes in genetic engineering, Chen suggests a conception of *experimental individuality* in experimental sciences and identifies three realization conditions that apply to these cases, namely *manipulation, separation*, and *maintenance of structural unity*.

In the final chapter (chapter 18), Steven French pleads for the elimination of the notion of individual in our scientific ontology. He starts with the observation that an eliminativist view of objects in physics has recently been suggested in the context of "ontic structural realism" (defended, in particular, by Ladyman and French: for overviews, see Ladyman and Ross 2007, French 2014). In this chapter, French explores the extent to which eliminativism can be articulated and defended in the philosophy of biology. Though the motivations are very different in these two sciences, French argues that a range of issues can be identified that pull us away from an object-oriented stance. He then suggests that various metaphysical resources can be deployed to help assuage concerns regarding such a move, and explores some of its consequences for the biological sciences.

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