Opening a Can of Spacetime Worms: The Metaphysics of Persistence

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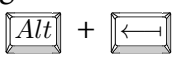
In the electronic version of this thesis, internal hyperlinks have been inserted to facilitate navigation. Internal links appear in this purple colour; clicking on the purple text will navigate to the relevant part of the document. For example, clicking on a citation will navigate to the relevant entry in the list of references. In all cases issuing a *back* command will navigate back to the point of origin. In most `.pdf` readers this can be achieved by the key combination 

Abstract

This thesis is composed of three essays on the perdurantist approach to persistence and identity over time. In Chapter 1, I discuss how the following papers are to be understood as parts of a unified perdurantist account of persistence over time. This chapter also outlines some of my philosophical assumptions and provides some background information about the metaphysics of persistence.

In Chapter 2, I respond to the objection that the worm theory is unable to account for our intuitions about ordinary counting sentences. I do this by invoking the standard linguistic phenomenon of covert quantifier domain restriction and supplementing the worm theory with situation semantics. My version of the worm theory makes our intuitive judgements come out true, and it does so well enough that there is no need to adopt the stage theory or revisionary theories of counting. Furthermore, my version of the worm theory offers a unified account of event- and object-related counting.

Chapter 3 focuses on a commonly neglected difference between different kinds of perdurantism, which are differences in mereological priority. I discuss three different views: parts-first perdurantism, no-priority perdurantism, and wholes-first perdurantism. I briefly outline all three views and some of the motivations for each of them. I fend off objections from and motivations for no-priority perdurantism. I also contend that intra-perdurantist debates about phenomenology ought not to be framed with respect to these forms of perdurantism. Instead, I suggest that the relativity of simultaneity presents an interesting scenario for parts-first and wholes-first perdurantists.

I respond to Thomas Pashby's arguments against the doctrine of temporal parts in Chapter 3. Pashby argues that metaphysicians ought to give an account of how quantum systems persist over time and that non-relativistic quantum mechanics is incompatible with perdurantism. I contend that his arguments rely on controversial, non-standard assumptions about the existence and importance of time observables. I demonstrate that perdurantists have no problem giving an account of how quantum systems persist over time in reference to an external time parameter.

Finally, I conclude with a summary of my arguments and some thoughts about directions for future research.

Declaration

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

I acknowledge that copyright of published works contained within this thesis resides with the copyright holder(s) of those works. I also give permission for the digital version of my thesis to be made available on the web, via the University's digital research repository, the Library Search and also through web search engines, unless permission has been granted by the University to restrict access for a period of time.

I acknowledge the support I have received for my research through the provision of an Australian Government Research Training Program Scholarship.

Danny George Wardle

Signature

03/03/2021

Date

We sometimes say: in later life I will be a different person.

— (Lewis, 1983a)

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Contents

Part I

INTRODUCTION

1

Introduction

The aim of this introduction is partly to contextualise the essays contained in the body text and to suggest how they form a unified whole. I provide some useful background information about the metaphysics of persistence. In particular, I provide a brief overview of the general debate between perdurantists and endurantists, along with some topics which I do not cover in the thesis proper. Then, I explain the format of this thesis and briefly outline the three essays contained within.

1.1 BACKGROUND AND ASSUMPTIONS

Perdurantists, also called *four-dimensionalists*, believe that objects persist by having different *temporal parts* at different times (Sider, 2001a). This notion of 'temporal parts' is sometimes thought to be deeply mysterious or needlessly complicated (Van Inwagen, 2000). However, there is a fairly simple way to understand what temporal parts are. Consider an ordinary person, Danny. Danny extends through space. We might think that Danny extends through space by having different spatial parts at each of his *subregions*. Some spatial parts of me (my feet) are located on the floor, whereas my head is not. We also have a neat way of explaining how I can have seemingly contradictory properties. I can be both cold and hot at the same time because part of me is cold and a different part of me is hot. Just as one might say that I extend through space by having different spatial parts, perdurantists believe that I extend through time by having different temporal parts.[1] The fusion of my temporal parts is called a *spacetime worm*. Perdurantism is also called *four-dimensionalism* or the *doctrine of temporal parts* (Sider, 2001a).[2] I use these terms interchangeably.[3]

The alternative to perdurantism is *endurantism*. Endurantism, put simply, is any theory of persistence which denies perdurantism. This termi-

1 What 'by having' is supposed to be doing in the explanation is something that I explore in Perdurantism and Priority.

2 Some people use the term *four-dimensionalism* to refer to the B-theory of time or the conjunction of the B-theory and perdurantism. Instead, I treat four-dimensionalism, pedurantism, and the doctrine of temporal parts synonymously.

3 Awkwardly, I favour the use of the term 'four-dimensionalism' in Counting for Worm Theorists while generally using 'perdurantism' in the other chapters. This is because I generally prefer using 'perdurantism', but I did not when I submitted the paper Counting for Worm Theorists for review. So, I have left that chapter unchanged.

nology and framing was originally introduced by Mark Johnston (1983) and popularised by David Lewis (1986). Endurantism is a view where things are 'wholly' present at each time they exist, rather than being 'partly' present in virtue of having temporal parts located at the various times they exist at. Endurantism is also called *three-dimensionalism*.

One of the main motivations behind metaphysical theories of persistence is the *problem of change*, also known as the *problem of temporary intrinsics* (Hawley, 2018: §3). Suppose I bought an unripe, green banana from the supermarket. Three days later, I notice that the banana has ripened and turned yellow. According to the law of non-contradiction, a single object cannot have incompatible properties. The banana, understood as a persisting entity, is technically both unripe and ripe. Now, obviously, this is no genuine contradiction because the banana is ripe and unripe at *different times*. But consider a slightly different case, where I leave the unripe banana on the table and someone replaces it with a very similar looking ripe banana. If I turned around straight afterwards, I would be able to figure out that the original banana has been replaced. In the original case, it is a lapse of three days which does not induce a similar belief. But why?

Some endurantists prefer an answer which appeals to an *A-theory* of time. The A-theory is the view that times are ordered by pastness, presentness, and futurity. This ordering is objective and, in their view, cannot be completely captured by tenseless propositions like 'The Banana was unripe on February 1, 2021.' and 'The Banana was ripe on February 3, 2021.' Reality *was* different in the past and *will be* different in the future. Some A-theorists, known as *presentists*, believe that only things in the present exist. They have the resources to say that what is absolutely true is what is true at some particular moment, and so deny that what obtains at any other moment is true. If the ripe banana is present and the unripe banana is not, then only the ripe banana exists and there is no problem of change. The banana is 'wholly present' and none of its parts are absent.

The A-theoretic response is quite radical and not without controversy. Most perdurantists and indeed many endurantists endorse the *B-theory* instead. The B-theory of time is the view that the past, present, and future are all equally real. Times are not ordered by past-present-future, they are ordered in a *tenseless* way. What is in 'the past' is simply 'earlier than' and what is in 'the future' is simply 'later than'. *Eternalism* is a popular B-theoretic view of temporal metaphysics in which the 'past', 'present', and 'future' all exist equally. Most of the ideas which I engage with in this thesis assume or at least assume compatibility with a B-theory of time.

Perdurantists have a solution to the problem of change which is compatible with the B-theory. On the perdurantist view, the banana has many temporal parts. The proper bearer of the properties 'being unripe' and 'being green' is an earlier temporal part, while the proper bearer of the prop-

erties 'being ripe' and 'being yellow' is a later temporal part. The banana changes over time in much the same sort of way that a road varies in its height as you drive along it. A road can be in a mountainous region and on flat fields because it has different spatial parts in those places. Similarly, the banana persists through change and time because it has different temporal parts at different times.

There is a semantic dispute between perdurantists about whether ordinary objects are the fusions of their temporal parts or simply brief temporal parts or *stages*. The former are known as *worm theorists* and the latter *stage theorists*. Some people choose not to consider stage theorists to be perdurantists and instead call them *exdurantists* (Haslanger, 2003). I explore the debate between stage theorists and worm theorists in more detail in Counting for Worm Theorists.

B-theoretic endurantists often deal with the problem of change by relativising properties to times. The banana is unripe on the first day and ripe on the third because it bears something like a 'being unripe-on' relation to the first day and a 'being ripe-on' relation to the third day. There is no contradiction here, the banana simply bears different relations to different things. A different endurantist approach is *adverbialism*. Adverbialists relativise *the ways* things instantiate different properties. The banana has the property 'being unripe' in a first day way and 'being ripe' in a third day way.

In an eternalist framework, it is hard to make sense of endurantism as a view where objects are 'wholly present' in the sense that all of its parts simultaneously exist. There are many cases where objects change because they lose or gain some parts. When a banana is plucked off of a banana tree, then it has changed because it lost one of its proper parts. If change by losing or gaining parts is possible, then many objects will fail to be wholly present on this view.

Worries about how to develop a B-theoretic endurantism that doesn't render change by loss of parts impossible has led to what Damiano Costa calls the *locative turn*. (Costa, 2017: 57) *Locative* endurantists hold that objects have many exact locations at many spacetime regions. This is an endurantist view because these regions are not temporal parts of objects. For an object to be wholly present at a region is for it to be exactly located at that region. Hence, locative endurantism provides the resources to say that objects are wholly present at each region they exactly occupy without rendering change by loss of parts impossible.

The standard alternative to this multi-location view is one where objects only have a single exact location. This view, often called *locative perdurantism*, is the view that objects are exactly located at their *path*. The path of an object is the region where its entire career is exactly located.

The terms 'locative endurantism' and 'locative perdurantism' are misleading. Hudson (2001) endorses a view where objects have multiple exact locations and have temporal parts. Similarly, one can believe that objects have a unique exact location and no temporal parts. These views are sometimes treated as hybrids of perdurantism and endurantism, but in my taxonomy they are not. The former view is a perdurantist one at heart and the latter is an endurantist one.

The view that objects are located at their path and have no temporal parts has received many different names in the literature. Cody Gilmore (2008) considers it a form of endurantism, as do I. Kristie Miller (2009) calls it *terdurantism*. Alessandro Giordani and Damiano Costa (2013) call it *temporal bare uni-locationism*. Pashby (2013; 2016) calls it *temporal holism*. Costa (2020) calls it *simplism*. Paul R. Daniels; Sam Baron and Kristie Miller (2019; 2019) call it *transdurantism*. While I consider this view to be a form of endurantism, I call it transdurantism throughout the thesis.

1.2 CONTEXTUALISING THE THESIS

This thesis is a collection of essays on *perdurantist* theories of persistence through time. This is not a traditional thesis, it is a thesis by 'publication format'. The thesis is not structured by a series of related chapters with an overarching argument. Rather, it is a collection of three essays which are largely independent from each other. The essays are such that they can be read on their own, without needing to read them alongside the introduction and conclusion or any of the other essays.

A minor downside of this is that the thesis involves some repetition. Some of the same ideas, like perdurantism, are briefly reintroduced in each chapter. The upside is that this format allows me to prosecute multiple self-contained arguments without the same kind of lengthy buildup and literature review expected in a conventional thesis. I am able to dedicate more of the thesis to specific contemporary issues and debates.

This is not a thesis wholly dedicated to solving the problem of change or providing a knockdown argument for perdurantism or against endurantism. The debate between perdurantism and endurantism has gone on for years. There are many highly sophisticated forms of perdurantism and endurantism that can stand up to intense scrutiny. I think it's unlikely that we'll make much progress by continuing to explore issues that have already been explored in great detail by many other philosophers. Much of the recent literature on persistence concerns very specific issues and debates over accounting for certain phenomena where small amounts of terrain are won and lost. In a weaker, but more personal sense, I think it's

unlikely that I will be able to make much of a genuine contribution to the debate in that way.

Instead, this thesis is composed of three different essays on a specific issue related to the metaphysics of persistence. While the problem of change has been thoroughly explored, many of the issues which I discuss have not. My approach is more fruitful because there is a lot more room for me to contribute to these specific debates than there is for me to contribute to the overall debate in a comprehensive way, especially in a project with the scope of a Master's thesis.

Each essay intersects with different related areas and topics in philosophy. The first essay, Counting for Worm Theorists, concerns a debate between different perdurantists about the best way to account for ordinary sentences about counting. This paper is at the intersection of metaphysics and philosophy of language. Similarly, Perdurantism and Priority connects perdurantist metaphysics with the literature on grounding and metaphysical dependence. In that paper, I also discuss some issues concerning temporal phenomenology and special relativity. The third essay, How (Quantum) Things Persist, is a response to some recent arguments that perdurantism is incompatible with non-relativistic quantum mechanics. So while this thesis is primarily about the metaphysics of persistence, I also seriously engage with some of the literature in philosophy of language and philosophy of physics.

The first essay, Counting for Worm Theorists, is a defence of the worm theory of perdurantist semantics. Specifically, I respond to the objection that the worm theory cannot account for our intuitions about ordinary counting sentences, such as 'there are two statues on the plinth'. I suggest that while Lewis's version of the worm theory is unsatisfactory, we can still salvage a different kind of worm theory. I appeal to the standard linguistic phenomena of context dependent quantifier domain restriction. We can make sense of sentences that require context to supply multiple domains of quantification with situation semantics. In the original problem cases for the worm theory, the problem is that the theory seems to predict that there are more objects than our intuitions suggest. If we can find a principled way to restrict the domain of quantification and reduce the number of spacetime worms to an appropriate amount, then we can overcome the apparent problems facing the worm theory. I introduce Sider's notion of maximal properties and argue that we count objects by maximal properties. Suppose that there is some situation in which a is the only F and some contextual shift generates a restriction to a subsituation. Some parts of a in the original situation won't be in the subsituation, so a will be absent. However, this doesn't mean that there are no Fs in the subsituation. A large part of a, the object b, can be a maximal F^* and can satisfy F when evaluated with respect to this subsituation. The relevant subsitua-

tion is fixed by context and is often explicitly laid out with phrases like 'tomorrow' and 'in the room'. This allows us to predict the truth of ordinary counting sentences in cases of fission and time travel without harming perdurantist ontology. By relying a little more heavily on the technical machinery of situation semantics, my version of the worm theory provides accurate predictions of 'event-related' counting sentences and a unified semantics of object-and event-related counting. My worm theory does well enough to eliminate old motivations for adopting a stage theory of counting. I argue that the standard version of the stage theory falls prey to similar problems as Lewis's worm theory. Furthermore, Emanuel Viebahn's sophisticated version of the stage theory is problematic because it requires him to posit an extra constraint on quantifier domain restriction and it isn't clear how his invocation of indeterminacy generates the right predictions. Ultimately, I demonstrate that the worm theory can provide a genuine account of our intuitions about ordinary counting sentences and does a better job than its stage-theoretic alternatives.

Perdurantism and Priority, focuses on the ways that perdurantist theories may differ with respect to their stances on metaphysical priority. I outline parts-first, no-priority, and wholes-first versions of perdurantism. Contra Valerio Buonomo and Mark Heller, I suggest that these views are generally compatible with both the stage theory and the worm theory. I argue that parts-first perdurantism ought to be considered the 'default' view, part of the general package of perdurantism and mereological universalism. A parts-first view plays a useful role in securing mereological innocence and by extension, the innocence of mereological universalism.

Then, I consider a version of wholes-first perdurantism where objects have temporal parts but persist in virtue of having a single, temporally extended exact location. However, I argue that this view seems to enjoy no serious advantage over transdurantism. We could also have a version of wholes-first perdurantism where objects still persist in virtue of their temporal parts. This may be preferable for some perdurantists who endorse restricted composition or priority monism. I suggest that no-priority perdurantism could potentially be motivated with an appeal to an apparent incompatibility between irreflexive priority and strict composition as identity. However, Roberto Loss develops a convincing reply to this argument.

Many perdurantists differ in their respective accounts of temporal phenomenology and both Buonomo and Heller claim that these differences emerge from differences between parts-first, no-priority, and wholes-first perdurantism. In contrast, I think that it is not clear that any particular phenomenological argument wins out. Furthermore, priority may not play any serious role in these debates in the first place. Where disagreements over priority do seem to matter is when considering some sce-

narios in Minkowski spacetime. The frame-relativity of simultaneity entails that temporal parts are not relativistically invariant, whereas four-dimensional entities are. I also consider an variation on an argument by Yuri Balashov which suggests that wholes-first perdurantism provides a superior explanation of why collections of three-dimensional shapes are unified in four dimensions. Despite this, I contend that both multilocative endurantists and parts-first perdurantists have a principled way to respond to Balashov. Furthermore, parts-first perdurantists can avoid the argument against the relativistic invariance of temporal parts by considering spatiotemporal parts in a relativistic setting. Parts-first perdurantists ought to endorse the priority of spatiotemporal parts, which can be temporal parts or spatial parts from different frames of reference, over their fusions. I conclude that perdurantists who endorse the general perdurantist package including the B-theory and mereological universalism ought to adopt spatiotemporal parts-first perdurantism.

In the final essay, I evaluate some recent arguments made by Thomas Pashby that perdurantism is incompatible with non-relativistic quantum mechanics. Pashby's arguments assume the eigenstate-eigenvalue link along with completeness, which rules out hidden variable theories like Bohmian mechanics. I outline Pashby's arguments, beginning with his first argument against quantum temporal parts. I reject Pashby's claim that the worm theory and the stage theory are committed to different pictures of quantum dynamics, since those views agree on the fundamental ontology. I also suggest that there are some problems with Pashby's attempt to develop a notion of quantum spatial parthood and by extension, quantum temporal parthood, by relativising parthood to location via a localisation scheme that implies quantum holism. Pashby argues that quantum temporal parts cannot obey temporal translation invariance due to a result known as Pauli's Theorem. This theorem rules out the existence of self-adjoint time operators T canonically conjugate to the Hamiltonian H, unless the Hamiltonian has a spectrum bounded from below.

I outline Pashby's second argument which does not rely on his notion of quantum temporal parts. Pashby's second argument relies on the same theorem as his first and provides a 'no-go' result for extended temporal parts. Then, I point out how Pashby's assumption that we ought to treat time as an observable motivates his move to an event-ontology. I argue that Pashby's event-ontology, which he calls reiterationism, is either an incredibly confused view or simply a view which collapses into perdurantism. Finally, I lay out how we could develop a perdurantist account of quantum objects with respect to external spatial and temporal parameters rather than a time observable. I defend this against Pashby's suggestion that this may violate the perdurantist commitment to a strong analogy

between space and time. I conclude that perdurantism is not incompatible with non-relativistic quantum mechanics.

These three essays comprise a unified whole in the sense that they are all concerned with perdurantist theories of persistence. This thesis, taken as a whole, is an attempt to clarify and refine perdurantism. The latter paper is relevant to the overall perdurantism-endurantism debate, since I defend perdurantism against the objection that quantum systems cannot have temporal parts. The other two are more relevant to intra-perdurantist debates. The first essay develops and defends a specific perdurantist approach to semantics. In the second, I develop on a commonly neglected distinction between different kinds of perdurantism in the second essay.

I hope that most of my use of logical symbolism is self-explanatory. In Counting for Worm Theorists, I make brief use of the lambda abstraction employed in situation semantics. In How (Quantum) Things Persist, I make some use of the Dirac notation ubiquitous in quantum mechanics.

Part II

BODY

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This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.

Signature

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Date

2

Counting for Worm Theorists

2.1 INTRODUCTION

Much of the ongoing debate between four-dimensionalists hinges on the semantics of counting. Many philosophers have argued that the worm theory fails to account for our intuitions about ordinary counting sentences (Hawley, 2001; Moss, 2012; Sider, 2001a; Viebahn, 2013). A popular move in the literature has been to abandon the worm theory in favour of a different theory, such as the stage theory. In this paper, I address the counting problems facing the worm theory and show that the worm theory can overcome them. I also argue that the existing alternatives are bested by my version of the worm theory.

In §4.2, I introduce the general topic of four-dimensionalist semantics and the worm theory. Then, I present the seemingly fatal cases of synchronic counting that challenge the worm theory. In §4.4, I begin developing my response to these counting problems by discussing the phenomenon of covert quantifier domain restriction. In §4.5, I argue that we count by sortals which usually designate maximal properties and that the worm theory successfully predicts this. In the following section, I explain the role that maximality and quantifier domain restriction play in my account. I demonstrate how my version of the worm theory predicts intuitive judgements about counting objects. In §3.7, I argue that the worm theory provides us with the best account of event-related counting as well. In §2.8, I explain why my version of a worm theory does a better job in fitting with our ordinary language judgements than the alternatives. I conclude that philosophers have prematurely discounted the worm theory and that we should never gave given up on it in the first place.

2.2 FOUR-DIMENSIONALIST SEMANTICS

Four-dimensionalism is the view that objects persist by having different temporal parts at different times. This is roughly analogous to how objects extend through space by having different spatial parts. Ideally, four-dimensionalists should be able to render all truths about the ordinary phenomena of persistence as truths in the four-dimensionalist language

of fundamental ontology.[1] Since there are intuitively true sentences involving persistence, four-dimensionalists need a philosophical semantics which uses their ontology to predict the truth of these sentences. The original four-dimensionalist semantics is known as the *worm theory* (Lewis, 1986: 202). Worm theorists claim that when ordinary speakers talk about objects that they are really talking about mereological fusions of temporal parts. These fusions are known as *spacetime worms*. The objects that we describe using predicates, refer to using ordinary terms, and quantify over using quantifiers are spacetime worms.

On the worm theory, 'River Torrens' seems to refer to the sum of its temporal parts. This sounds fine so far, but how does the worm theory deal with indexicals and demonstratives? To illustrate this, let's consider a situation where a speaker observes the River Torrens flooding and makes a series of utterances:

(1) a. The River Torrens is flooded.
    b. That is flooded.

(2) a. That persists through time.
    b. The River Torrens persists through time.

The meaning of a specific use of a demonstrative like 'that' is usually mediated by a certain causal interaction. This causal interaction is between the speaker and some temporal parts which are concurrent with the utterance. Most four-dimensionalists accept *unrestricted mereological composition*, which is the view that there exists an arbitrary mereological sum for every plurality of objects. This means that there are many different mereological sums which have the concurrent temporal parts of the River Torrens as parts.[2] Hence there are multiple candidate referents for a demonstrative, so which candidate is the referent of a specific use of 'that' needs to be determined by the context of the utterance. This is a problem if the standard contextual mechanisms we use, like disambiguating reference by spatial location, cannot resolve the ambiguity.

The worm theory predicts the meaning of complex sentences by figuring out whether the predicate used can be satisfied by a short-lived stage of an object or only by an object throughout its entire existence. We can make sense of this disjunctive approach by using the stage- and individual-level predicate distinction (Carlson, 1977). For a predicate to be stage-level means that it is satisfied by a temporal stage of an individual. In the case of (1a), the predicate 'is flooded' is stage-level because it is

1 It would be very costly if four-dimensionalists needed to accept extensive revisions in ordinary judgement, although see Moss (2012) for a four-dimensionalist error theory of ordinary counting.

2 This holds for anyone who accepts unrestricted mereological composition, not just four-dimensionalists.

satisfied by a limited part of the River Torrens's lifespan. Lingering predicates like 'is flooding' are also stage-level for the same reason. In the case of (2b), the predicate 'persists' is satisfied at all times where the River Torrens exists. So, predicates like 'persists' and 'is a river' are only satisfied at the individual-level. Both stage-level and individual-level predicates can be held by spacetime worms of differing durations, but the way that predicates get satisfied by objects differs depending on whether a stage- or individual-level predicate is used. At the individual level, this is very simple. (2b) is true *iff* the River Torrens has the property of *existing at more than one time*, which it clearly does. Dealing with stage-level predicates is a little more complicated. (1a) is true *iff* the River Torrens has the complex property of *having a temporal part which is flooded* at the time of utterance.

2.3 COUNTING WORRIES FOR THE WORM THEORY

If we ask something like, 'How many things exist?', the worm theorist responds, 'However many (fusions of) temporal parts exist'.[3] We get this answer because terms for ordinary objects denote spacetime worms, so variables that range over persisting things can be allocated to any spacetime worm of arbitrary duration. Two spacetime worms are identical *iff* they share the exact same parts.[4] Ordinary conversations don't normally make use of an unrestricted domain of quantification. An unrestricted quantifier domain is useful for philosophical discussions regarding fundamental ontology, but it is rarely employed in ordinary conversation.

Ordinary counting involves counting the number of ordinary things that satisfy a specific sortal predicate. For some ordinary counting questions, the worm theory seems to provide unintuitive answers. Specifically, the worm theory struggles with cases of coincidence and fission.

Suppose that we observe a single boat, known as 'Popeye', traversing the River Torrens. Now, let's also suppose that this is a case of fission where Popeye, 'like an amoeba, divides' (Parfit, 1984: 254). Popeye is about to split symmetrically into two boats, although it hasn't undergone fission yet. Even before it does, the worm theory predicts that the answer to (4a) is 'two' while the intuitive answer is 'one':

(3) a. How many boats are traversing the River Torrens?
b. One. / #Two.

The worm theory also struggles to deal with cases of coincidence. Consider the famous case of Lumpl and Goliath (Gibbard, 1975). An artist

3 In fact, all four-dimensionalists who accept classical mereology will have this answer.
4 This includes spatial as well as temporal parts.

takes a lump of clay and names it 'Lumpl'. Then, the artist sculpts the Biblical figure Goliath out of the lump. Now we have two things, Lumpl and Goliath, which occupy the same space at the same time. There are two salient spacetime worms sharing the relevant temporal part in that region. We have Goliath and then we have Lumpl, which came into existence before Goliath and is therefore distinct from it.[5] When Lumpl and Goliath coincide, the worm theory predicts that the answer to (4a) is 'two'. However, there is some intuitive appeal in being able to say that there is only one thing there and that the lump of clay *is* the statue:[6]

(4) a. How many things are there?
b. One. / #Two.

The problem is clear: the worm theory provides us with inaccurate predictions about our ordinary counting judgements. The most well-known attempt at a defence of the worm theory comes from David Lewis. In response to these problems, he outlines a novel theory of counting. Lewis argues that we often count two non-identical objects as one and the same:

> If an infirm man wishes to know how many roads he must cross to reach his destination, I will count by identity-along-his-path rather than by identity. By crossing the Chester A. Arthur Parkway and Route 137 at the brief stretch where they have merged, he can cross both by crossing only one road. Yet these two roads are certainly not identical. (Lewis, 1983a: 63–4)

In the same way that we count overlapping roads as one road, we also count overlapping boats as one boat. Here we count, not by strict identity, but by a looser relation like identity-along-our-path. We count things by our encounters with them. This normally gives the same predictions as the view that counting is by identity, except in these weird cases of coincidence and fission. Lewis' view is often conceived as a semantic theory where the truth conditions of ordinary counting sentences are never given in terms of strict identity.[7] If we take Lewis' theory as a purely semantic one, then we are left with a deeply revisionary view of counting. Many philosophers are unwilling to accept this approach. Sider explicitly states that 'part of the meaning of 'counting' is that counting is by identity' (Sider, 2001a: 189) In the literature on the semantics of counting sentences, it is almost always assumed that we count by identity. Lewis' the-

5 They are also distinct because they have different *modal properties*. Lumpl can survive being squashed but Goliath cannot.

6 There is a separate, extensive discussion regarding how to make sense of this answer (Lewis, 1983a; Unger, 1979; Wiggins, 1968). Regardless, it is undeniable that 'one' has some *prima facie* appeal as an answer to (4a).

7 As opposed to the tenseless counting sentences uttered by metaphysicians, which do concern strict identity.

ory of counting does avoid the problem, but at the cost of rejecting this assumption.

López de Sa argues that Lewis' view might be more accurately understood as a purely pragmatic theory (López de Sa, 2014). On this view, our intuitive answers to questions like (3a) and (4a) are false, strictly speaking. However, our intuitive answers are still 'true enough' in ordinary contexts. Loosely counting by relations of partial indiscernibility instead of strictly counting by identity is appropriate in most conversations. This pragmatic reading of Lewis leaves us with a slightly different theory. We normally count by identity, but sometimes we approximate by weaker relations. Our counting judgements are strictly false but loosely true. Still, this theory is unsatisfactory. First, we don't have a great idea of how strictly false claims become loosely true and what 'loose truth' even is when it comes to counting. This account also fails to give us any genuine predictions about ordinary counting sentences. Instead, we're left with an ad-hoc account which tells us that we normally count by identity but do something else whenever the worm theory seems to run into problems. The pragmatic view is revisionary because it tells us that, in certain cases, we aren't 'really' counting properly even if we think we are. Furthermore, it is unclear what mechanisms we can use to predict loose readings of counting sentences. Both the semantic and pragmatic view leave four-dimensionalists with plenty to worry about.

Metaphysicians have largely abandoned the worm theory in the face of these problems.[8] However, I suggest that the worm theory has been too readily dismissed. I argue that the worm theory, once supplemented with some fairly standard linguistic machinery, can provide a genuine account of ordinary counting.

2.4 QUANTIFIER DOMAIN RESTRICTION

Counting sentences evince a kind of context dependence. Specifically, I contend that the kind of context dependence they exhibit can induce quantifier domain restriction. The phenomenon of quantifier domain restriction is a standard feature of ordinary discourse. Consider an ordinary utterance of (5):

(5) Every bottle is on the shelf.

Intuitively, there are true utterances of (5). For (5) to turn out true doesn't require every bottle in the world to be on the shelf, because *every* quantifies over relatively few of the world's bottles. So, it follows that

8 See (Hawley, 2001), (Moss, 2012), (Sider, 2001a) and (Viebahn, 2013) for examples.

we evaluate utterances of sentences with quantified expressions with respect to restricted quantifier domains and that context supplies the domain (Stanley and Williamson, 1995: 291).

Counting sentences also exhibit quantifier domain restriction. Consider the example of an utterance of (5) followed by an utterance of (6):

(6) There are billions of bottles.

This would be infelicitous, since there aren't billions of bottles sitting on the shelf in the domain contextually determined by (5). If counting sentences weren't subject to contextually fixed domain restriction, then the invariant domain for bottles would have to contain relatively few of the world's bottles. Hence, there would be no true utterances of (6). Since there are, it's clear that counting sentences do exhibit quantifier domain restriction. Consider a simple counting sentence like:

(7) There exist n Fs.

In some context c, (7) expresses the proposition: in domain d, there are n (non-identical) Fs.

There are cases where simple quantifier domain restriction doesn't work. Suppose that a group of party goers discuss the behaviour of the guests after a party. Alice and Bob were both uninvited gatecrashers who annoyed all of the invited guests. Someone utters:

(8) Exactly two people annoyed everyone.

Intuitively, there is a reading of (8) which is true even if Alice and Bob didn't annoy each other (or themselves). To explain (8), we need context to supply multiple domains (Soames, 1986: 357). More specifically, we need to arrive at something like: 'in domain d^1, there are exactly two people who annoyed everyone in domain d^2'.

One way of dealing with (8) is by employing *situation semantics* (Kratzer, 2019). In situation semantics, sentences are evaluated with respect to a mere part of a possible world or a *situation*. In accounting for sentences like (8), many versions of situation semantics suggest associate an implicit situation variable with noun phrases while also allowing for verb phrases to introduce an implicit situation variable associated with the topic situation (Kratzer, 2019). The topic situation of (8) is merely the part of the world where the party took place. (8) is true *iff* exactly two people annoyed everyone in the part of that situation which only includes the invitees. To account for 'donkey anaphora' like 'Every man who owns a donkey beats it', predicates have covert situation arguments in the syntax. Roughly put, this means that different predicates in a single sentence can be evaluated with respect to different situations. Situation semantics

gives us exactly what we need. We have a plausible mechanism that can reproduce our intuitive judgements. In the remainder of this paper, I'll be making use of situation semantics – albeit without relying too heavily on the technical details.[9]

The familiar phenomenon of quantifier domain restriction allows for utterances structured along the lines of 'There are exactly n Fs' to be true so long as the context allows us to neglect counting non-salient Fs which aren't in the topic situation. Quantifier domain restriction is exactly what the worm theory needs to deal with both problem cases. Recall that in the coincidence and fission cases, the worm theory counted two distinct spacetime worms. In the domain of the entire world, it is true that there really are two distinct spacetime worms in both cases. However, if ordinary counting sentences under discussion exhibit quantifier domain restriction, then the worm theory might be able to predict the truth of our ordinary judgements about counting. This is regardless of whether there really are multiple objects in those cases on a fundamental level.

In both problem cases, the worm theory seems to predict that there are more objects than our intuitions suggest. The obvious move here is to restrict the domain of quantification and reduce the number of spacetime worms until we predict the right amount. In the following sections, I will explain precisely how context dependence operates in both cases and how this all works in relation to the worm theory. To start with, I will introduce *maximality* and how it relates to the sortal predicates featured in ordinary counting sentences.

2.5 COUNTING SORTALS AND MAXIMALITY

A property F is maximal *iff* large parts of any F aren't themselves Fs (Sider, 2001b: 357). For example, *being a chair* is maximal while chair-minus, a thing that shares all the parts of a chair aside from a single leg, isn't a chair. Chair-minus is really just a large part of an object which *is* a chair. In fact, Sider notes that many ordinary sortal predicates designate maximal properties (Sider, 2001b: 357). Large proper parts of people, dogs, cats, houses etc. aren't themselves people, dogs, cats, houses etc., so these properties are maximal.

For any maximal property F there is a related possibly non-maximal property, *F**. x is an *F** *iff* there is some possible situation in which an intrinsic duplicate of x is F. In the chair example, chair-minus is a chair* because there is a possible situation where the chair's leg was removed

9 One might want to use Stanley and Szabó's *covert domain variable* approach instead (Stanley and Szabó, 2000). This makes no serious difference to my arguments; situation semantics just makes some things easier to explain.

and there would be a chair which is an intrinsic duplicate of the present chair-minus. In other words, chair-minus could turn out to be a chair if things go the right way.

Ordinary counting judgements are fairly intuitive. Ordinary counting questions usually involve someone asking how many people, dogs, cats, houses etc. there are in a given situation. And we do tend to find that answering these questions is fairly straightforward. If the ordinary sortals involved in counting were non-maximal, we would find such questions very puzzling. Suppose that we observed a lone chair and were asked to count the number of things that satisfied chair*. The chair could lose a leg, an armrest, its upholstery and so on, while still satisfying chair*. The same is true for other objects too. So, we would end up with answers that are very different to the ones that we normally provide and those answers would be far more difficult to figure out. This all suggests that we count objects by maximal properties and not by their related intrinsic non-maximal properties. When we count objects, we usually count by sortals which usually designate maximal properties.

The worm theory predicts this. Four-dimensionalist ontology entails that there are arbitrary temporally extended parts of spacetime worms. If *being a chair* was a non-maximal property, then the worm theory should entail that for every chair, there are many chairs whose entire lives are identical to some long part of the original chair. No worm theorist would endorse this, so they need to hold that counting sortals are maximal in order to provide the right predictions for any counting sentences.

2.6 COUNTING OBJECTS

Recall that four-dimensionalism posits the existence of arbitrary mereological sums of temporal parts. Variables take such things as values and these values are restricted quantifier domains. Noun phrases are associated with an implicit situation variable, while verb phrases introduce an implicit situation variable which is associated with the topic situation. In all cases, restriction is encoded by evaluating the restricted expressions at a sentential or subsentential level with respect to a salient subsituation. The upshot is that the quantifier domain can have less of the simplest temporal parts than the amount included in the 'fundamental' domain. In virtue of this, the domain of entities quantified over contains fewer mereological sums because all appropriate domains of any subsituation are usually closed under arbitrary mereological fusion and decomposition. However, sometimes we might want to omit counting these arbitrary fusions and so we can have some domains of subsituations which aren't closed under fusion.

Now, I will explain the role that maximality plays in my account. Suppose there is some situation in which a is the only F and some shift in the context generates a restriction to a subsituation. Some parts of a, which were in the original situation, will be absent from the subsituation. Hence, a itself will be absent. However, this doesn't necessarily entail that there are no Fs in the subsituation. This is because an object b, which is a large part of a and is an F^*, is present in the restricted domain. Object b can be a maximal F^* because there is no y such that $b + y$ is F^* in the subsituation. When we evaluate b relative to this subsituation, it can satisfy F. In other words, objects which aren't F may nevertheless be sufficient to satisfy F when evaluated relative to a subsituation.

The relevant subsituation is fixed by context. In some cases, the temporal location of the situation is explicitly laid out using phrases like 'yesterday', 'within the next hour' and so on. In other cases like (5) ('Every bottle is on the shelf.'), the use of the present tense informs us that the topic situation is a present one. Without any other topical current situation, the utterance situation is the obvious fallback. The explicit spatiotemporal boundaries of utterance situations are unclear. We do know, however, that (5) can be uttered truly in some brief window of time between cases where all the bottles aren't on the shelf. So, we still know that these spatiotemporal boundaries can be as restrictive as we need them to be.

All of this allows the worm theory to adequately deal with both problem cases. Consider the coincidence of Lumpl and Goliath. Now, suppose that we point to the plinth and say:

(9) There is exactly one object on the plinth.

(9) is true *iff* there is only one thing in the relevant situation. The present tense of the utterance means that the situation must be a present one and 'on the plinth' explicitly provides the spatial location of the relevant situation. Hence, the present situation in (9) is that part of the world including only the plinth at the present moment. In that situation, there is only one object: a lone, maximal spacetime worm which is a shared part of Lumpl and Goliath.[10] This also makes the following utterance true:

(10) The lump of clay on the plinth is identical to the statue on the plinth.

(10) turns out true because the referents of those sortal descriptions are two spacetime worms which are restricted to the present situation. When restricted, those two sortal descriptions pick out the same single spacetime worm. One might worry that this solution creates a difficulty

10 Ignoring the micro-level objects that we usually neglect to count like arbitrary fusions of molecules and the coincident Lumpl/Goliath.

thanks to the modal differences between lumps of clay and statues. The lump of clay can survive being squashed, but the statue cannot. In this restricted situation, the shared temporal part of the lump and the statue turn out to be both a lump and a statue. So, we need to invoke *modal counterpart theory* to explain how maximal spacetime worms get their modal properties (Lewis, 1968).

On modal counterpart theory, an object x has the property of *possibly being F iff* a counterpart of x in some possible world has F. We can apply modal counterpart theory to this case. In a world where the coincident Lumpl and Goliath are squashed, the counterpart of Lumpl persists and the counterpart of Goliath doesn't. Lewis notes that unlike identity, any counterpart relation 'will not, in general, be an equivalence relation' (Lewis, 1968: 115). So, we can account for sentences like (10) along with sentences like 'the lump of clay on the plinth will survive squashing, while the statue will not'. We could also deal with the modal differences between lumps of clay and statues by appealing to the less-restricted worm of which they are part.

The fission case can be dealt with in a similar way. Suppose that we observe Popeye traversing the River Torrens before it undergoes fission and that we utter the following:

(11) There is exactly one boat traversing the River Torrens.[11]

(11) is true *iff* there is only one boat in the relevant situation. Again, the present tense and explicit spatial location provide us with the relevant situation. In the relevant situation, there is only one maximal spacetime worm because the future temporal parts of the fissioned boats aren't included.

The role that tense plays in fixing the topic situation ensures that most present tense claims will have very brief topic situations. Ordinary counting sentences like (11) have topic situations too brief to include instances of objects undergoing fission or coincident objects diverging. Thanks to role that maximality plays in my account, the maximal spacetime worm in (11) can instantiate the individual-level predicate 'boat'. In these cases, we avoid double-counting overlapping objects in ordinary quantifier domains.

One might raise an apparent problem case for my view as I've developed it so far. Specifically, this is a problem for combining my proposal about how tense and aspect determine the relevant quantifier domain with the worm theory. Suppose that in the coincidence case, Lumpl was immediately dug out of the ground and placed on the plinth. After a reasonably long time, the artist shapes Lumpl into Goliath. Following this,

11 Here, the stage-level predicate 'traversing' takes precedence over the individual-level predicate 'boat'.

nothing else ever happens to the plinth and the coinciding Lumpl/Goliath. Then, someone utters:

(12) a. Only two things have been on that plinth.
b. They won't always be there.

Intuitively, (12b) is false because we know that the object on the plinth will always be there. However, 'it' anaphorically refers back to the thing under discussion in (12a). If the 'one thing' in (12a) is a maximal day-long spacetime worm, then it really won't be there tomorrow and (12b) will turn out true. My response to these sorts of problems is to suggest that sentences like (12b) misfire since they implicitly force (12) as a whole to share a topic situation which concerns every time.

Ignoring this problem case, I've successfully dealt with most cases by reducing the number of objects which satisfy a specific sortal predicate. Let's consider a different case where the restriction of situation doesn't involve this. Suppose that someone spends their entire life confined to a room that no one else may enter. In the room, this person develops a time machine and travels back to an earlier point in their life. Then, they spend one hour chatting with their past self. Intuitively, the following two claims about this situation are correct:

(13) a. One time, there were two people talking to each other in the room.
b. There has only ever been one person in the room.

(13a) concerns a brief, past situation in the room. It is true *iff* there was ever a situation in which two people conversed with each other. By restricting the time-traveller's parts to that time where they temporally overlap themselves, we get two maximal spacetime worms. In contrast, (13b) concerns a situation including all times at which the room exists. In that situation, there is only one maximal spacetime worm. The situation that we must evaluate (13a) with respect to is a part of the larger situation which (13b) is concerned with. Here, the domain of the smaller situation is a subset of the larger domain.

2.7 COUNTING EVENTS

So far, we've been counting objects. Many of the previously discussed cases posed a *prima facie* problem for the worm theory because our intuitive judgements suggested that there were less objects present that than worm theory seemed to predict. After supplementing the worm theory with an appropriate understanding of how ordinary counting sentences

exhibit quantifier domain restriction, these cases no longer pose a problem.

However, there are other kinds of ordinary counting which have motivated a move away from the worm theory. Consider the following famous example:

(14) Four thousand boats passed through the lock last year (Krifka, 1990).[12]

Manfred Krifka argues that (14) has two readings (Krifka, 1990). The first is the familiar object-related reading. In that reading, we count four thousand distinct boats which passed through the lock last year. In the other reading, we count the number of lock traversals by boats rather than the number of boats. This other reading doesn't entail the existence of four thousand distinct boats, since there may well have been some boats which passed through the lock twice during the last year. In much the same way, an airline might report that they had two million passengers last year and count repeat journeys by the same passenger as multiple passengers. These counting sentences are known as *event-related* counting sentences, since we seem to be counting events rather than objects.

Event-related counting sentences are a problem for the worm theory because the temporal location of the topic situation is explicitly provided by 'last year'. So, (14) is about a year-long situation and we can restrict the domain of quantification to spacetime worms in said situation. However, doing this means that we won't correctly count the boats that make multiple lock traversals. This presents a problem for getting the required event-related reading as a possibility.

Perhaps we can get the event-related reading by evaluating the predicates in (14) with respect to a situation different from the topic situation of the entire sentence. In order to explain how we can do this and how it might help, let's consider a straightforward counting sentence about teapots:

(15) a. There are three teapots.

b. $\lambda s \exists x(x \leqslant_p s \wedge |\{y : y \leqslant_p x \wedge \text{teapot}(y)(s)\}| = 3)$.[13] (Kratzer, 2019: §7)

12 The original example refers to 'ships', while I say 'boats' in keeping with the Popeye fission case discussed earlier in the paper.

13 Note: the meaning of a sentence is a function from situations to truth values. $\lambda x F$, where x is the only free variable which occurs in F, designates the function that maps a to $\top$ *iff* a has the property expressed by F. The reason for doing things like this is that linguistic expressions can be given a function as their semantic value – and not just functions from entities to truth values. Furthermore, the syntactic composition of expressions can be mirrored by successive nested instances of functional application. (15b) is an open sentence with a covert situation variable and not a closed sentence. '$\leqslant_p$' denotes the 'part of' mereological relation.

Here, (15b) describes a property of a situation s that has three parts as teapots, relative to s. (15a) is true, relative to s, *iff* there is a part of that situation which has three parts and those parts are teapots. 'Teapot' is a standard sortal predicate and hence, it is also maximal. (15b) evaluates whether an object satisfies the sortal 'teapot' with respect to situation s, which is normally the topic situation of (15a).

Correspondingly, (14) has the following formal semantics in lambda notation:[14]

(16) $\lambda s \exists x \big(s \leqslant_p \text{last year} \wedge x \leqslant_p s \wedge \big|\{y : y \leqslant_p x \wedge \text{boat}(y)(s) \wedge \text{traversed the lock}(y)(s)\}\big| = 4000\big)$.

(16) tells us that there is part of the topic situation of (14) including four thousand boats, which are distinct with respect to the topic situation s. In that subsituation, each distinct boat makes a lock traversal. We can also provide a different reading of (14), where the situation variable associated with 'boat' is bound by the implicit situation quantifier ∃x and not by the lambda operator:

(16′) $\lambda x \exists x \big(x \leqslant_p s \wedge |\{y : y \leqslant_p x \wedge \text{boat}(y)(x) \wedge \text{traversed the lock}(y)(x)\} = 4000\big)$.

Now we can consider a scattered situation which only includes the parts of the world where lock traversals take place.[15] This scattered object contains four thousand lock traversals as parts, which leaves us with a maximal spacetime worm for each lock traversal. Each maximal spacetime worm does not stand in the correct same-boat-as relation to any boat in any other traversal of the lock. Many of the boat parts needed for multiple candidate boats to stand in the correct genidentity-constituting relation over time are absent from this subsituation. Chris Barker notes that these parts are absent because basic logistics entails that there is a fairly long interval between two lock traversals made by a single boat (Barker, 1999). Since maximality does not prevent us from counting what are fundamentally proper parts of boats as boats, we can count four thousand boats in this subsituation. One might notice that this is similar to what was happening with (13a): 'One time, there were two people talking to each other in the room.' In (13a), we could get the intuitive count by counting what are fundamentally proper parts of persons in a restricted situation.

14 'Boat' is a two-place predicate here because a boat is only a boat relative to a situation where there is no bigger part of it present.

15 We shouldn't do this in all cases. If there is a case where four thousand boats traverse two locks in a lock system, we still might want to be able to say 'four thousand boats passed through the lock last year'. In that case, the situation under consideration won't be a scattered one.

I've explained how this sort of reading is plausible; My next task is to explain why we really *should* evaluate the sortal predicate 'boat' in (14) with respect to a restricted situation. My reasoning in this case is this subsituation is fairly intuitive. Suppose that someone was stationed at the lock last year. Presumably, that person is in a great position to evaluate claims with respect to this particular subsituation. In fact, they would probably have a much easier time evaluating claims with respect to this subsituation rather than the topic situation. This is because boats are difficult to conclusively reidentify, especially given that there are fairly long intervals between two lock traversals. It makes more sense to count by easily discriminated boat traversals with a common spatial location than attempt to track boats over the long periods of time where they are absent from the lock. My explanation about why this subsituation is a natural candidate to saturate the situation variable on 'ship' is very similar to an explanation offered in support of Barker's account:

> It is no accident that the best examples of this phenomenon concern situations in which there are too many individuals to keep track of easily…In [(14)], for example, logistical facts guarantee that a given ship will return to the lock only after several weeks' worth of similar vessels have passed through. (Barker, 1999: 689–90)

In Barker's account, this means that when we fail to recognise that two stages are part of the same object then our semantic interpretation should make the same mistake. He simply adds this constraint as an additional rule. Instead, I hold that the epistemic situation we find ourselves in makes it appropriate to evaluate sentences with respect to certain epistemically available subsituations. Epistemically available subsituations in any given context are naturally available to saturate situation variables. A minor advantage of my account over Barker's is that it provides this explanation of why and how these epistemic factors play such a role.

Admittedly, my account of event-related counting is more reliant on the technical machinery of situation semantics than preceding sections of this paper. As such, my account of event-related counting is more vulnerable to criticisms of situation semantics. There is one key advantage of exploiting the formal apparatus of situation semantics in my account. Namely, my account renders event-related counting an ordinary kind of object-related counting. We count ordinary objects that satisfy ordinary sortal predicates in my account of 'event-related counting'. The two readings of the sentence are predicted by the different binding of the covert situation variables in the syntax. Another advantage of my view over Barker's is that we don't need to invoke any extra novel semantic tools. Barker's account, like mine, permits context to to fix the extension of predicates like 'boat' and also requires ordinary counting sortals to be maximal. The issue with Barker's account is that he needs to provide a disjunctive in-

terpretation of the quantifiers. In his account, operators can 'quantify either over individuals or over stages of individuals, subject to pragmatic appropriateness' (Barker, 1999: 684). In contrast, my account entails that quantifiers always range over boats. Combining covert domain restriction with maximality just sometimes happens to permit some things which are boat*s to be maximal boats. This isn't dissimilar from Barker's view that 'boat' sometimes refers to a boat-stage, but my account avoids invoking a disjunctive interpretation of quantifiers. Another issue with Barker's account is that he invokes different kinds of 'identity' relations. Sometimes we count by boat stages and sometimes we count by boats. This seems to run into the same worry that befell Lewis' revisionary theory of counting. Counting, by definition, is by strict identity and not by other relations.

This is all well and good, but then how do we explain utterances of 17?

(17) Four thousand *different* boats passed through the lock last year.

Barker claims that 'different N' subsumes the different stages of the same N into one (Barker, 1999: 690). This identity criterion works for his view, which allows us to sometimes count by boat stages even when boats are in the domain of quantification. (17) forces us to count by boats instead of boat stages. In my account, there really are four-thousand, non-identical boats in the epistemically relevant subsituation. To deal with sentences like (17), I suggest that 'different N' forces us to evaluate the situation variable attached to N with respect to the topic situation and not the subsituation. This gives us the right predictions in these cases.

There is another apparent problem case regarding event-related counting:

(18) a. Four thousand boats passed through the lock last year.
b. Half of them paid a fee at the next harbour (Barker, 1999: 689).

This problem is intuitively similar to the previously considered problem for combining my proposal about how tense and aspect fix the relevant domain of quantification with the worm theory. 'Them' in (18a) anaphorically refers back to the boats in (18a) but 'boats' in (18a) seems to pick out boats that only only last as long as a single lock traversal. If we count boats that are too short-lived to pay a fee at the next harbour, then (18b) will always turn out false on my account. Intuitively, however, there are true utterances of (18b). I suggest that as long as the boats we count in (18a) don't last over two traversals, there is no reason why we cannot say that some of them last beyond a traversal. Presumably, epistemically salient situations can include boats that persist long enough to satisfy the predicate *traversed the lock and paid a fee at the next harbour*.

Admittedly, I don't have a principled explanation of how this works in regards to the formal semantics. Nevertheless, my account does not suffer too much in the face of these problems because other approaches also struggle to account for anaphora like (18b).

For example, Moss offers a counterpart-theoretic treatment of problem cases like (18). In her view, we could say that (18a) and (18b) are both about the same objects. She invokes the existence of *temporal counterparts* and suggests that (18b) is true just in case the boats we talk about in (18a) stand are the past temporal counterparts of the boats that pay a fee at the next harbour. This might be a convenient response, but it seems to violate the rule that counting is by identity and not any counterpart-theoretic surrogate for identity.

One might object that my account is not a genuine worm theory. Consider the following argument against the worm theory made by Moss:

> The objects we ordinarily talk about are the same sort of objects we talk about with event-related counting sentences...[and] the objects we talk about with event-related counting sentences are proper temporal parts of individuals (Moss, 2012: 676).

In the context of Moss' paper, the domain of quantification is unrestricted. In that particular context, Moss is right to point out that the objects we talk about using event-related counting sentences are proper temporal parts of individuals. She is also correct to say that the objects we normally talk about, at least by metaphysics paper context standards, are proper temporal parts of individuals. However, these observations don't disadvantage the worm theory. The worm theory is the view that ordinary continuants are spacetime worms. The worm theory does not entail that if something is a maximal F-satisfying spacetime worm in one context, then it is a maximal F-satisfying spacetime worm in all contexts. On my account, the worm theory is the view that the objects that we ordinarily quantify over in a context are the objects that satisfy maximal predicates in that particular context. The worm theory is consistent with Moss' claims being true in the context of utterance. Furthermore, it would be very odd if the worm theory was incompatible these claims. Consider the fact that most worm theorists are committed to unrestricted mereological composition. This means that, in a metaphysics context, there are many objects quantified over of which almost any spacetime worm we pick out is a proper part.

Outside of this special context, it is misleading to say that the objects we discuss using event-related counting sentences are proper temporal parts of individuals. Ordinary counting sentences are evaluated with respect to restricted domains of quantification. These quantifier domains tend to only include maximal individuals, at least for ordinary sortal predicates.

Being an individual that gets quantified over just happens to be context-sensitive. That is a fairly unsurprisingly consequence, once we consider the standard linguistic phenomenon of quantifier domain restriction.

2.8 THE STAGE THEORY

The standard four-dimensionalist alternative to the worm theory is the *stage theory* (Hawley, 2001; Sider, 2001a). While the worm theory says that the objects we discuss are spacetime worms, the stage theory says that the objects we discuss are temporal stages. Recall that the worm theory gave a simple semantics for individual-level predicates and a slightly more involved semantics for stage-level predicates. The stage theory makes the opposite trade off here. Sentences involving ordinary stage-level predicates are true *iff* the stage under discussion has the relevant property. In contrast, dealing with individual-level and lingering stage-level predicates is more convoluted. To provide a semantics for those predicates, the stage theory posits the existence of temporal counterparts. For a sentence involving those predicates to turn out true, the current stage under discussion needs to have temporal counterparts that collectively stand in the right kind of relations to satisfy the relevant predicate. In the case of persistence, an object persists *iff* it exists and it has at least one counterpart at a distinct time.

Temporal counterpart theory is controversial. One may suggest that the stage theory entails that there is no such thing as persistence. If we talk about stages which are generally bound to a temporal instant, and there are no objects at a later time that are identical to any current stage, then it seems like nothing persists after all. This is known as the Humphrey objection and it applies to all forms of counterpart theory (Kripke, 1980). However, it is not obvious that the stage theory entails nihilism about persistence. Sure, no current object is strictly identical to any future object. Nonetheless, the natural language predicate 'is the same as' does not need to denote strict identity and can denote a relation that holds between stages.

The stage theory has no problem accounting for the fission and coincidence cases. If the sentences in these fission cases quantify over instantaneous stages, then we get the intuitive answers without difficulty.

However, the stage theory runs into its own class of counting problems. Consider a non-fission case where we observe the lone 'Popeye' traversing the River Torrens for an hour and someone asks:

(19) a. How many boats were traversing the River Torrens during the last hour?

b. One. /# Infinitely many.

If we count instantaneous temporal stages, then there will be infinitely many of them that satisfy the predicate *is a boat* within the last hour. It is not easy to respond to this problem by employing covert quantifier domain restriction. Since the stage theory needs individual stages to satisfy predicates like 'is a boat' or 'is a person', then any temporally extended situation will involve counting many more things than an ordinary person would. Even versions of the stage theory that allow stages to be temporally extended run into this problem, since any temporal interval that includes an intrinsic change in any object's properties will generate a problem. Without modifying the stage theory, the only potential solution would be to propose that every sentence, including those with explicit temporal situations, have a temporally unextended subsituation which provides the domain. This an unsatisfying solution, especially since it is hard to see what semantic mechanism can give us that.

A more plausible view is Viebahn's *indeterminately relevant* stage theory (Viebahn, 2013). Viebahn's account begins by positing a basic constraint on quantifier domain restriction in order to predict the right counts:

> BASIC CONSTRAINT: The domain of any ordinary use of a quantifier contains at most one stage out of any maximal class of suitably counterpart-interrelated stages (Viebahn, 2013: 314).

When counting the number of boats that were traversing the River Torrens during the last hour, we only count one boat per maximal class of appropriately counterpart-interrelated stages. A stage is relevant for an utterance of a counting sentence if is located in the quantifier domain of that sentence or it has suitable temporal counterparts in the domain. We can arrive at the intuitive answer of 'one' in the case of (19) because there is one class of counterpart-interrelated boat stages that have appropriate counterparts during the last hour. So, we count exactly one relevant boat stage.

Viebahn invokes indeterminacy when he argues that it is indeterminate which stages are relevant in regards to a counting sentence, so long as a maximum of one stage out of any maximal class of counterpart-interrelated stages is relevant. One of the reasons he invokes indeterminacy is to deal with cases where we might want to predict more than one answer. Recall the Lumpl and Goliath case discussed earlier in the paper. When someone looks at the plinth and asks, 'how many things are there?', we might reply with 'one' or 'two'. On one reading, this case is concerned with one maximal class of counterpart-interrelated stages. The relevant stage in one class is located at a time where Lumpl and Goliath coincide, so it must also be the relevant stage for the other class and the answer is 'one'. However, on Viebahn's account it is indeterminate which individual stage is counted. Someone might ask, 'how many things are there?',

but be particularly concerned with the modal distinction between Lumpl and Goliath. In these circumstances, the relevant stages for both classes are located at times where they don't coincide. So 'two' will be the appropriate answer (Viebahn, 2013: 321). The same goes for our boat fission case. If we observe 'Popeye' traversing the River Torrens yesterday and it undergoes fission this morning, Viebahn suggests we can answer 'how many boats were traversing the River Torrens yesterday?' with 'two' if we are concerned with current boats.

It is unclear how indeterminacy generates these results. In the coincidence case, it seems determinate that utterances of 'two' must pick out stages that aren't shared by both Lumpl and Goliath. In the fission case, it also seems determinate that utterances of 'two' must pick out stages temporally located after fission. It is unclear what semantic mechanism allows sentences explicitly about 'yesterday' to pick out stages located at a different interval. If it truly is indeterminate which stages are relevant, then we don't have a reliable means of predicting 'one' or 'two' depending on context. Instead, it seems that the answer must always be indeterminate between 'one' and 'two'. In contrast, my account provides a semantically principled means of predicting the right counts in different contexts without invoking indeterminacy.

A more minor worry is that Viebahn's view that we count one individual stage per maximal class of counterpart-interrelated stages is less intuitive than the worm theory. In cases of temporally extended situations, it makes more sense to claim that we usually count temporally extended objects instead of counting some indeterminately located maximal classes of counterpart-interrelated stages.

My most serious worry is that Viebahn's basic constraint is semantically unprincipled. Viebahn wants to count by identity and not by some kind of counterpart-theoretic surrogate for identity. So, he posits the basic constraint to force the domain of quantification to only include one stage per maximal class of suitably counter-interrelated stages. However, Viebahn offers no semantically principled reason for adopting the basic constraint. The basic constraint is simply posited so that stage theorists can avoid overcounting.

In contrast, my account doesn't involve positing any extra constraint on quantifier domain restriction. With an appropriate understanding of situation semantics and maximality, my account can generate the appropriate counts without requiring any ad-hoc or novel constraints.

2.9 CONCLUSION

I have mounted a successful defence of the worm theory and demonstrated that it can provide a genuine account of our intuitions about ordinary counting sentences. I have done this by invoking the standard linguistic phenomenon of covert quantifier domain restriction and supplementing the worm theory with situation semantics. My version of the worm theory makes our intuitive judgements come out as true, while also offering a unified account of object- and event-related counting sentences. Furthermore, the worm theory does better a better job than its stage-theoretic alternatives and revisionary theories of counting.

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Perdurantism and Priority

3.1 INTRODUCTION

In this essay I focus on a commonly neglected difference between different kinds of perdurantism, which are differences in mereological priority. In this paper, I discuss three different views: parts-first perdurantism, no-priority perdurantism, and wholes-first perdurantism. I briefly outline all three views and some of the motivations for each of them. I fend off objections from and motivations for no-priority perdurantism. I also contend that intra-perdurantist debates about phenomenology, which have been framed with respect to these forms of perdurantism in the past, ought not to be. Instead, I suggest that the relativity of simultaneity in Minkowski spacetime presents a more interesting scenario for these disagreements about priority.

3.2 MEREOLOGICAL PRIORITY

Mereology is the study of part-whole relations. When thinking about the metaphysics of parts and wholes for ordinary objects, mereology plays a crucial role. Of particular importance to metaphysicians are issues concerning how, when, and why parts compose or constitute a mereological whole. The most infamous problem regarding mereological composition is the *special composition question*: Under which conditions do some parts *x* compose y?

The two 'radical' responses to the special composition question are *mereological nihilism* and *mereological universalism* (Varzi, 2019: §4). Mereological nihilists reject parthood. There are no circumstances under which some parts *x* compose y. Mereological universalists run in the opposite direction. They believe that composition is *unrestricted*. For any two objects, there exists a further object that is composed of the two. The vast majority of perdurantists endorse mereological universalism.[1] Perdurantists with a temporal parts ontology without committing to the existence of spacetime worms or *nihilist stage theorists* should endorse mereological nihilism or a restricted mereology that excludes spacetime worms.[2] Mereological nihilism is a very natural, parsimonious choice for the nihilist

1 See (Lewis, 1986), (Hawley, 2001), (Sider, 2001a) for some prominent examples.
2 See (Patrone, 2020) and possibly also (Sider, 2013).

stage theorist. It is harder to see how one might justify a nihilist stage theory while permitting other fusions and it may be difficult to justify that kind of view.[3] There are also a minority of moderate perdurantists, such as Yuri Balashov (2003), who endorse some restrictions on diachronic fusions.

Another key issue is the problem of *mereological priority*. This problem is about whether there is any relation of priority between proper parts and wholes.[4] Do wholes exist in virtue of their parts, do parts exist in virtue of their wholes, or is there no priority relation involved in parthood? Initially, the first answer seems most tempting: parts compose wholes, so wholes ontologically depend on their parts. It's fairly intuitive to think that a house is built out of bricks and that those bricks 'come before' the house.

On the other hand, one might think that *structured wholes* or *genuine unities* pose a counter-example. Neo-Aristotelian hylomorphists, for example, think that a whole is not merely a collection of material parts. Rather, genuine unities also have a form or some essential principle of unity. Some people might think that the bricks, even though it is somehow important to the house, is less fundamental than more abstract features like its social function or its shape.[5] We can also consider priority monists, who believe that the universe as a whole is basic and that its parts are derivative.[6] Even then, these views do not entail a full-blown wholes-first theory of mereological priority. Most hylomorphists have not endorsed a wholes-first view and priority monism only requires that the universe is a whole which grounds the existence of its parts (Schaffer, 2010a). It may be the case that structured wholes are prior and their parts are posterior, but the opposite may apply to mere arbitrary fusions.

But what exactly is *priority* supposed to be? A fairly natural way to cash this out would be in terms of *grounding*. My talk of things existing or having some property *in virtue of* something else is amenable to most no-

3 One strategy might be to think that fusion can take place *at* times but not *across* times. That way, we would have a sharp principled distinction between permissible and impermissible fusions that permits a stage theory. This might not be a bad option, since stage theorists tend to take 'unity' over time as something to be cashed out counterpart theoretically anyway.

4 Any notion of priority between improper parts and their wholes would be difficult to make sense of. I assume that priority is irreflexive, that is to say, something cannot be more fundamental than or be prior to itself. I generally use 'part' throughout this paper to mean 'proper part'.

5 See (Armstrong, 1986), (Fine, 2010), (Koslicki, 2018) for some examples of Neo-Aristotelian views.

6 (Schaffer, 2010a) is an example of a modern priority monist. Significant antecedents may include classical philosophers like Parmenides and Plotinus, along with modern philosophers like Baruch Spinoza and Georg Wilhelm Friedrich Hegel. See (Joad, 1957) and (Schaffer, 2010b) for some thoughts on the history of priority monism.

tions of entity grounding.[7] I take it for granted here that grounding imposes a strict partial ordering on the things in its domain. In other words, grounding is asymmetric, irreflexive, and transitive. My goal here is not to defend a specific version of grounding or argue that some particular form of grounding is the best for explaining mereological priority. If you find grounding unattractive, feel free to treat my talk of priority as talk about a more palatable irreflexive relation.[8]

Alternatively, one may reject any notion of mereological priority. There is no priority relation that comes pre-packaged with the theory of mereolgy, understood as first-order logic plus some primitive relation and some definitions. If we define parthood in terms of overlap, which might be more intuitively read as a relation between entities at the same level, then our mereology might not involve any priority at all.[9] One might want to keep a 'neutral' theory of mereology without adding other relations like grounding. There are also worries that irreflexive notions of priority are incompatible with various premises that we need to secure classical mereology (Bailey, 2011). Moreover, there are metaphysical skeptics who are wary of 'dark notions' of metaphysical priority *tout court* like Judith Jarvis Thomson (Thomson, 1983: 211).

I will address some of these issues in this paper. In what follows, I apply the question of mereological priority to perdurantist theories of persistence. I outline *parts-first*, *no-priority*, and *wholes-first* theories of perdurantism.[10] Following this, I contend that intra-perdurantist disagreements about temporal phenomenology are not illuminated by appeals to metaphysical priority. Finally, I discuss some issues regarding relativity that might be of more significance here.

3.3 PRIORITY PERDURANTISM

One option is the view that temporal parts are more fundamental than spacetime worms. We could call this *parts-first perdurantism*. For example, the temporal parts of a chair are more fundamental than the spacetime worm that they compose.

At first glance, any alternative direction of mereological dependence may sound nonsensical. Rejecting parts-first perdurantism might sound somewhat counterintuitive, since perdurantism is typically outlined as

7 See (Fine, 2012), (Rosen, 2010), and (Schaffer, 2009b) for some examples.

8 For example, one might cash things out in terms of a family of ontological dependence relations or essence dependence instead of grounding (Tahko and Lowe, 2020).

9 In a similar way, we can see how taking proper parthood or fusion as primitive might provide some weak motivation for priority.

10 I use this terminology instead of 'stages-first' and 'worms-first' in order to avoid confusing these views with the stage theory and the worm theory, which are related but distinct positions.

the view that objects persist by *having* temporal parts. This may seem to suggest that temporal parts are metaphysically prior to their fusions. However, the notion that objects must *have* temporal parts is not a definition. Rather, it's a useful way to express the claim that: necessarily, some object persists through some interval of time t iff there are parts of that object (call them 'temporal parts') at each time in t. This is perfectly compatible with various theses about metaphysical priority, including wholes-first perdurantism.

We have a necessary biconditional: An object perdures through T *iff* it has a distinct part occupying each timeslice of T. But then we might wonder: What way, if any, does priority run?

But there are good reasons to consider parts-first perdurantism to be the default perdurantist view. It is generally taken for granted that temporal parts are more fundamental than spacetime worms.[11] This seems like a view that has been implicitly endorsed by many perdurantists, despite the fact that it has rarely been explicitly defended. One exception would be Ryan Wasserman, who argues that the explanatory value of perdurantism is derived the view that objects depend on their temporal parts to persist through time (Wasserman, 2016). The perdurantist account of temporary intrinsics is one where objects have their temporary properties indirectly and their parts have those properties directly. Perhaps it is only a short leap from that to the claim that temporal parts are prior to their fusions, in general. Parts-first perdurantism also seems to reflect the more general claim that temporal instants or 'moments' are prior to temporal intervals. Moments can be built up out of scattered spatial facts and then we can build an interval out of those moments. This is the standard *instant-based* approach of tense logic (Goranko and Rumburg, 2020: §2). This is in contrast to an approach more favoured by many A-theorists: the *intervals-based* approach.

What seems to be the main motivation behind parts-first perdurantism and parts-first mereology in general is its role in securing the *ontological innocence* of mereology. Central to David Lewis's defence of mereological universalism is the notion that mereology is *innocent* (Lewis, 1991: 81-7). Committing ourselves to the existence of plenitudinous fusions is not costly because wholes are 'nothing over and above' their parts. The view that wholes are exhaustively grounded in their parts is a useful way to secure mereological innocence.

This kind of neat explanation is not readily available to wholes-first perdurantists, who seem to face many additional pressures to reject mereological universalism. However, one might think that the wholes-first perdurantist could adopt a view where parts are 'nothing under and below'

11 See (Lewis, 1986), (Sider, 2001a), and (Hawley, 2001) for examples.

their wholes which secures mereological innocence. If we take some mereological universalist model as given, then we could accept the doctrine of arbitrary undetached parts to entail the existence of many arbitrary parts. We might then justify that doctrine on the basis that parts are merely wholes divided. On this wholes-first view, the doctrine of arbitrary undetached parts would motivate innocence rather than the other way around. I am not so concerned with whether this explanation works as I am with the many additional reasons why mereological universalism is a bad fit for wholes-first perdurantism, which I discuss later on.

The view that all parts are prior to their wholes is fairly popular, with Aaron Cotnoir even claiming that it is part of the 'default view' of the world (Cotnoir, 2013). One might think that there is no uniquely perdurantist path to parts-first pedurantism, but that it simply falls from the priority of parts *simpliciter*. Parts-first perdurantism fits nicely what I call the 'standard perdurantist package' which comes along with mereological universalism and a B-theory of time. Most perdurantists endorse these views and it's fairly easy to see why.[12] Mereological universalism plays an important role in standard perdurantist semantics and in dealing with paradoxes of coincidence, since it gives us many linguistic candidates to work with. The B-theory provides a natural motivation for perdurantism, which gives us temporal parts alongside spatial parts. If the B-theory of time is true, then we need a theory of persistence which does not appeal to a metaphysically privileged present.

Another thought might be that this seems to be a common view because most theories of mereology begin by taking parthood or proper parthood as basic and then defining other mereological relations such as fusion in terms of them (Parsons, 2014). However, this sort of claim is about *conceptual priority*. What we take as primitive in our conceptual schemata might simply be things that we understand and are familiar with, rather than more metaphysically fundamental things.

Parts-first perdurantism retains compatibility with different kinds of perdurantist semantics and other modified forms of perdurantism. Parts-first perdurantism is compatible with the stage theory, which is the view that the ordinary objects we discuss are temporal stages. Since parts-first perdurantists think that temporal parts are prior to spacetime worms, it fits quite naturally with the stage theory. However, parts-first perdurantism is also perfectly compatible with the worm theory. Parts-first perdurantists are still committed to the existence of spacetime worms. There is no reason why the priority of temporal parts over the perdurant wholes they compose ought to rule out the worm theory. Consider the

12 (Sider, 2001a) and (Hawley, 2001) are influential examples of contemporary perdurantists who are like this.

'standard' parts-first perdurantist worm theory: parts are prior to wholes, but natural language designators refer to the derivative wholes. The debate between the stage theory and the worm theory concerns natural language, not ontology. The additional claim that natural language designators must latch on to more fundamental entities is not entailed by any form of perdurantism.[13] However, one could also adopt a deflationary form of parts-first perdurantism where spacetime worms are not counted in the domain of unrestricted quantifiers. This sort of approach would put significant pressure on its adherents to adopt the stage theory.

We could also consider an extreme form of parts-first perdurantism, which we might call *parts-only perdurantism*.[14] On this view, there are no fusions of temporal parts. There are only temporal parts.[15] This view is more restrictive than regular parts-first perdurantism, since it entails a nihilist form of the stage theory. Those who endorse the nihilist stage theory or *pixelism* are parts-only perdurantists.[16]

Another option would be the inverse one: the view that perdurant wholes are more fundamental than temporal parts, or *wholes-first perdurantism*. We can formulate this view in a few different ways. One might be a wholes-first perdurantist and still commit to the claim that objects metaphysically depend on their temporal parts to persist through time. Even these perdurantists rely on temporal parts to do most of the heavy lifting in their accounts of persistence. Following Valerio Buonomo, we can distinguish between *persistence dependence* and *existential dependence*:

PERSISTENCE DEPENDENCE: x depends for its persistence on y.[17]

EXISTENTIAL DEPENDENCE: x depends for its existence (simpliciter) on y (Buonomo, 2018: 74).

Perdurantists that include temporal parts and spacetime worms in their ontology generally seem to accept the claim that spacetime worms persist *in virtue* of having temporal parts. Parts-first, wholes-first, and non-priority perdurantists disagree on the issue of existential dependence. Parts-first perdurantists hold that spacetime worms ontologically depend on

13 Thankfully so, as it would lead to deeply revisionary judgements about ordinary language use.

14 This is technically a form of no-priority perdurantism. There is no relation of priority between temporal parts and their fusions, since the fusions do not exist.

15 Names like 'temporal parts' and 'temporal stages' are unfortunately somewhat misleading, since they aren't parts or stages of any whole.

16 Fabio Patrone (2020) is one example. Ted Sider, who has previously defended stage-theoretic perdurantism and mereological nihilism, albeit separately, may be another example (Sider, 2001a; 2013).

17 If ordinary objects persist *essentially*, then we could treat persistence dependence as a kind of essence dependence.

their temporal parts. Wholes-first perdurantists believe the inverse: that temporal parts exist in virtue of spacetime worms. Non-priority perdurantists deny that there is any existential dependence between temporal parts and spacetime worms. Just as mereologists who take parthood as basic might find parts-first perdurantism appealing, those who take fusion as basic instead might find wholes-first perdurantism appealing.[18]

One might suggest that Storrs McCall (1994) argues for a form of wholes-first perdurantism where temporal parts are abstractions derived from four-dimensional objects. He takes four-dimensional objects as basic and suggests that they have a natural shape corresponding to sortal predicates. Quite clearly, McCall's view differs from the mereological universalist approach taken by most other perdurantists. McCall considers temporal parts to be abstractions 'in the way that the earth's equator and meridian lines are abstractions' (McCall, 1994: 211).

This reveals a tension between the mereological picture of perdurantism and the locative picture. For the former, a parts-first ontology seems like the best fit. For the latter, the claim that objects persist by having temporal parts is coupled with the view that objects are exactly located at a four-dimensional region. Those who take the latter claim more seriously than the former might be tempted by this kind of wholes-first view.

However, are serious issues with taking McCall's view to be a form of perdurantism. Kristie Miller (2006) points out that McCall's view that temporal parts are merely a conceptually convenient way of dividing up entities is a form of anti-realism about temporal parts.[19] If temporal parts are like meridian lines, then they are nothing like the concrete property-bearing entities that perdurantists commit themselves to. Rather than seeing McCall as a wholes-first perdurantist, I suggest that it makes more sense to see him as a *transdurantist*. Transdurantists are like perdurantists in that they believe ordinary objects *extend* through spacetime, but like endurantists in that they do not endorse the doctrine of temporal parts (Baron and Miller, 2019: 180).

If endurantism is defined as a rejection of the doctrine of temporal parts, then transdurantists simply *are* endurantists. Since wholes-first perdurantism is a form of perdurantism, it is absolutely committed to the existence of temporal parts. In contrast, parts-only perdurantism is still a form of perdurantism.

But we can consider a wholes-first view where objects do not perdure *in virtue* of their temporal parts. Suppose that we endorse perdurantism

18 Both (Fine, 2010) and (Kleinschmidt, 2019) take fusion as basic instead of parthood.

19 We could adopt a kind of plenituduous or idealist view where we think that if there exists some conceptual mechanism for dividing an object O into 'parts', then there exist some parts of O corresponding to that division. Such an option is not available to McCall, since it clearly conflicts with his deflationary approach.

for *locative* reasons. We think that objects have a single four-dimensional location and that the fundamental properties are distributional properties of regions. On this view, objects perdure *in virtue* of being four-dimensional. They still have temporal parts, but this is just an additional consequence of having a four-dimensional location. If objects just had many different three-dimensional locations, then they would not have temporal parts and they would not perdure. This fits with the earlier necessary biconditional: on this view, an object perdures through T *iff* it has a distinct part occupying each timeslice of T. We can make sense of this kind of view by considering Antony Eagle's definition of an S-region:

> [An S-region is] a maximal temporally unextended subregion of a location [...] That captures precisely the intuitive concept of an instantaneous spatial location: namely, it is the region which is the overlap (intersection) of a temporally extended location with a particular time [...] It follows immediately from this that, if an object has just one location, it has just one S-region at a time, because intersection is a function (Eagle, 2010: 67-8).

In Eagle's view, S-regions are derived from locations. If we then define a temporal part as the occupant of an S-region, then we get temporal parts from the level-neutral principle that every filled region is exactly occupied by something.

If we think that only views where temporal parts need to play a special role in explaining persistence are perdurantist, then this kind of wholes-first perdurantism is not perdurantist. Perhaps endurantism is simply the denial of the view that things persist *in virtue* of their temporal parts and it doesn't entail the denial of temporal parts in general. But I don't think that revising our taxonomy in this way is a principled thing to do. Perdurantism would be rendered an incredibly specific view whereas endurantism would encompass a variety of very different views. One could be an endurantist and endorse a view which includes temporal parts alongside a very perdurantist-friendly locative account or a completely different view where temporal parts do not exist and objects have multiple three-dimensional locations, which seems very odd.

A more serious worry for this kind of view is that it enjoys no serious advantage over transdurantism. If temporal parts play no special explanatory role and what matters is that objects have a unique four-dimensional location, then why have temporal parts in the first place? We have an answer to the problem of change invoking distributional properties of regions, so it seems that temporal parts don't play any meaningful role here. Temporal parts are already controversial and there's hardly any reason to keep them if they aren't needed. If this kind of wholes-first 'perdurantist' chooses to become a transdurantist, then they can make their view more palatable to those who are hostile to any notion of temporal parts while

not sacrificing any explanatory power. So this view ought to collapse into transdurantism. As such, I believe that any wholes-first *perdurantist* is best off endorsing a view where objects persist *in virtue* of their temporal parts but are nonetheless more fundamental than them in existential terms.

Wholes-first perdurantism is a difficult position to formulate. This is for several reasons. Firstly, a universal theory of wholes-first perdurantism does not play well with mereological universalism. Most perdurantists endorse mereological universalism and unrestricted mereological composition. One clear worry here is that wholes-first perdurantism and unrestricted composition leads to a metaphysics where there are many perdurant wholes more fundamental than their temporal parts. Consider the infamous 'trout-turkey', a mereological fusion of a trout and a turkey. In this case, let us assume we're fusing one of the trout's temporal parts and one of the turkey's temporal parts. Under wholes-first perdurantism, the trout-turkey turns out to be more fundamental than its parts. This seems deeply counter-intuitive. If *all* wholes are more fundamental than their parts, then we're left with a metaphysics with a bizarre chain of priority.

This would also seem to commit the wholes-first perdurantist to a more costly version of priority monism. If perduring sums are more fundamental than their parts, then the Spinozan whole (the universe) must also be more fundamental than its parts. This is a more costly view than priority monism because most versions of priority monism do not commit themselves to the priority of all fusions over their parts, just the priority of the Spinozan whole over its parts (Schaffer, 2010a). If wholes-first perdurantists want to avoid these issues, then they need to reject unrestricted composition or endorse a weaker version of wholes-first perdurantism that only applies to some spacetime worms under specific conditions.

Buonomo (2018) takes the both paths, endorsing wholes-first perdurantism in regards to persons while remaining neutral as to the direction of priority for other persisting objects. He also endorses a distinction between mere sums and structured wholes where the latter are more fundamental than their temporal parts. This is a kind of restricted composition view, since not all things have a fusion which is a structured whole. Buonomo believes that this provides his version of wholes-first perdurantism with an advantage over parts-first and no-priority perdurantism (Buonomo, 2018). I disagree. Requiring additional metaphysical assumptions in order to render wholes-first perdurantism viable seems like more of a disadvantage than anything else, especially since other perdurantists could also choose to endorse a distinction between mere sums and structured wholes. Furthermore, structured wholes-first perdurantism seems to be committed to an unattractive semantics of ordinary counting. They are pressured to adopt a worm-theoretic semantics, but their commit-

ment to the priority of structured wholes may also prevent them from adopting the kind of covert quantifier domain restriction-sensitive worm theory that I outline in Counting for Worm Theorists. If ordinary objects are structured wholes and not the plenitudinous sums of unrestricted composition, then it may be costly to also endorse contextually maximal wholes to explain ordinary counting sentences.

I think there are better ways to formulate a version of wholes-first perdurantism. One need not endorse a distinction between mere sums and structured wholes to think that only some wholes are prior to their parts. Priority monism is one example of a wholes-first metaphysics which is radically inegalitarian about which wholes are fundamental. They believe that the cosmos itself is the only fundamental object. Schaffer (2009a) accepts both priority monism and perdurantism. He is also a *supersubstantivalist*, which means that he believes that spacetime is a fundamental substance and that material objects are identical to the spacetime regions they occupy.[20] Perdurantists who are also priority monists might have good reason to be wholes-first perdurantists.

Some of the motivations for priority monism and wholes-first perdurantism are shared. For example, both priority monism and wholes-first perdurantism are able to account for the possibility of *gunk* in the same way. Gunk is matter which does not bottom out into indivisible simples, it is *atomless* (Schaffer, 2009a). Every part of a gunky object has further proper parts. If gunk is metaphysically possible, then metaphysicians need to account for it. With parts-first views, we end up with an endless chain of metaphysical dependence. Things get more and more basic as you divide them into further parts. On this view, nothing would ultimately turn out to be basic at gunky worlds. If nothing is basic, then there is no ultimate ground. Without an ultimate ground, then things look bad for any irreflexive notion of metaphysical priority. Of course, the parts-first perdurantist could respond by claiming that their theory need not be true at all worlds. If the actual world is not gunky, then parts-first perdurantism isn't under too much of a threat. In contrast, wholes-first perdurantists have no problem accounting for the possibility of gunk. If we think that we need our explanations to terminate somewhere, then it seems natural to think that the endlessly divisible parts of gunky objects metaphysically depend on their wholes.[21]

20 This is in contrast to both dualistic *substantivalism* (the view that both objects and spacetime regions are two different kinds of fundamental entities) and *relationalism* (the view that spacetime is merely derivative).

21 The other option for the parts-first perdurantist is to deny that we need an ultimate ground. Perhaps our explanations don't terminate and we do have an endless chain of metaphysical dependence after all.

While wholes-first perdurantism might be attractive to perdurantists who endorse priority monism, they are not forced to adopt it. One might endorse a view where the cosmos is prior to its parts and most temporal parts are prior to their wholes. This would turn out to be a view where the cosmos is the only spacetime worm prior to its parts.

3.4 PERDURANTISM WITHOUT PRIORITY

One might instead be a no-priority perdurantist and reject any relation of priority between temporal parts and spacetime worms. On this view, temporal parts and their fusions are not metaphysically dependent on each other for their existence. Ordinary objects still persist in virtue of having temporal parts, but they are not any more or less basic in the existential sense. Mark Heller (1990) is a no-priority perdurantist. For him, 'temporal parts and the wholes that they compose are ontologically on a par' (Heller, 1990: 22).

Like parts-first perdurantism, no-priority perdurantism is compatible with a range of different perdurantist views. No-priority perdurantism is compatible with the worm theory and the stage theory. It is not compatible with pixelism and unlike parts-first perdurantism, it is not compatible with deflationary versions of the stage theory which treat spacetime worms as dispensable derivative entities.

While a parts-first view is often assumed to be the default view, one might note that classical mereology is neutral on the issue. If the theory of mereology is a topic-neutral application of first-order logic with identity, then perhaps we should avoid baking our metaphysics into our mereology. One might reply that we could still endorse a direction of mereological priority without seeking it in the first-order language, or reject the assertion that mereology is topic-neutral. While mereological priority may be controversial, it is still largely regarded as the default view.

Furthermore, it is worth noting that metaphysical priority is also accepted in set theory. The inclusion relation between members and classes is considered one where the members are ontologically prior to their classes (Lewis, 1991). Again, this is not part of set *theory* proper. We need not decide to take the iterative conception of set to capture dependence. But the set-theoretic parallel is constructive, since Boolos uses the iterative conception of set to motivate the content of set-theoretic axioms (Boolos, 1989).[22] Likewise, Lewis seems to use a parts-first picture to moti-

22 Of course, set theory is explicitly generative in a way that parthood is not. The singleton a is very different from the set a, but the degenerate fusion of the parts b is just b again. So one might argue that the extremely thin way in which fusions are distinct from the parts they fuse is a reason for treating them as ontologically on par. This is not the case, however, for proper parts.

vate mereological universalism. If a fusion is 'nothing over and above' its parts, then they are no novel addition to reality. We can accept mereological universalism without cost if we already accept a parts-first mereology. However, if wholes are substantive entities not reductively grounded in their parts, then it's harder to see how we get them for free in the way that Lewis envisages.

Strict *composition as identity* is another way to try to account for the innocence of mereology. Composition as identity is the view that mereological composition *is* identity. The whole is identical to the sum of its parts. Mereological sums are not anything above their parts because they just *are* the same thing. Composition as identity gives us a simple and illuminating explanation of these two features of mereology without needing irreflexive priority.

Andrew M. Bailey (2011) has argued that irreflexive priority theories are incompatible with strict composition as identity. Hence, those who endorse strict composition as identity might have an additional reason to reject parts-first and wholes-first views in favour of no-priority perdurantism. I note that Bailey's argument only challenges *strict* forms of composition as identity. There are also weak forms of composition as identity where composition is *like* identity but is not strict identity in the sense of '='. Let's state Bailey's argument against parts-first mereology as applied to priority perdurantism:[23]

(1) Danny is a spacetime worm composed of his temporal parts t_1, t_2, and t_3. (Assumption)

(2) Danny is identical to his temporal parts t_1, t_2, and t_3. (1, Composition as Identity)

(3) The temporal parts t_1 t_2, and t_3 are ontologically prior to Danny. (1, Parts-First Perdurantism)

(4) Danny is not identical to his temporal parts t_1 t_2, and t_3. (3, Irreflexivity of Priority)

(5) Danny is identical and not identical to his temporal parts t_1 t_2, and t_3. (2, 4)

While I have stated this argument in reference to parts-first perdurantism, the same result applies to wholes-first perdurantism. Rejecting the irreflexivity of priority is not an option, as (Bailey, 2011: 172) points out that this would entail that all mereological sums are prior to themselves. We could avoid this argument by rejecting the strict version of composition as identity and instead adopting a weaker view such as weak com-

23 The original argument is stated purely in terms of classical mereology, but the form of the argument remains the same here.

position as identity. This is the view that composition is merely analogous to identity in some way. Rejecting composition as identity may not be a problem, especially since many philosophers already do so.[24] Besides, mereological priority can also account the intimacy and innocence of mereology. Maybe the parts are prior to the wholes in a way that ensures the properties of the wholes flow from the collective properties of the parts. Parthood is ontologically innocent because the whole is derived from its parts. If parts-first and wholes-first theorists need to reject composition as identity, then so much the worse for composition as identity.

Alternatively, we could follow Roberto Loss (2016) in arguing that priority is actually compatible with composition as identity. Loss distinguishes between *collected pluralities* of parts and *scattered pluralities* of parts (Loss, 2016). We can think of a collected plurality of temporal parts as something like 'the collected tp plurality' as a single entity and which feature in propositions like 'the collected tp plurality exists'.[25] In contrast, scattered pluralities of parts take their parts individually like 't_1, t_2, and t_3' and which feature in propositions like 't_1 exists, t_2 exists, t_3 exists'.

On Loss's view, composition as identity is secured because mereological wholes are identical to their parts taken as a collected plurality of facts. The fact that Danny exists is identical to the fact that In contrast, priority obtains from the fact that the parts, taken as a scattered plurality, are prior to their fusion. We can sketch this out in terms of priority perdurantism as follows:

(6) Danny is a spacetime worm composed of his temporal parts t_1, t_2, and t_3. (Assumption)

(7) The scattered plurality of temporal parts t_1 t_2, and t_3 are ontologically prior to Danny. (1, Parts-First Perdurantism)

(8) The fact that Danny exists and the fact that the collected plurality of his temporal parts exist is the same fact. (1, Composition as Identity)

(9) Danny is not identical to the scattered plurality of his temporal parts t_1 t_2, and t_3. (2, Irreflexivity of Priority)

However, one might respond by claiming that this still leads to a contradiction. If I am not identical to the scattered plurality of my temporal parts, then surely I cannot also be identical to the collected plurality of my temporal parts. If this is true, then we are back to square one. Fortunately, Loss (2016: 492) suggests that this inference relies on a principle that we can avoid endorsing. He contends that this inference relies on the idea

24 Including perdurantists like (Lewis, 1991) and (Sider, 2007).
25 Where 'tp' denotes 'temporal parts'.

that if x is identical to some collected plurality (the ys), then the proposition 'x exists' is identical to the scattered plurality (of propositions) 'y_1 exists, y_2 exists, etc.'. From this principle and (9), one can make the valid inference that I am not identical to the collected plurality of my temporal parts, which contradicts (8). Loss suggests that that this principle is derived from composition as identity and an additional, similar principle. This second principle is that if x is identical to the ys, then the proposition 'x exists' is merely the fusion of the propositions 'y_1 exists', 'y_2 exists' etc. It is true that these propositions will compose a whole which, under unrestricted composition and composition as identity, they will be identical. However, Loss argues that we need not take the fusion of these propositions to be the proposition 'x exists' (Loss, 2016: 493). He suggests that there are plausible cases where someone believes the proposition 'x exists' without believing every individual proposition 'y_1 exists', 'y_2 exists' etc. For example, one might believe that the moon exists but have no belief about the existence of some of the moon's parts. So strict composition as identity and mereological priority are compatible.[26]

In hindsight, objections like Bailey's were always going to come up when considering one-many identity in the setting of strict composition as identity. In one-one identity, if F_a and $\neg F_b$, then $a \neq b$. But if $A = b, c, d$ and F is the predicate 'are many', then a isn't many while b, c, d are.

3.5 PHENOMENOLOGY

One significant way in which different kinds of perdurantism tend to vary is in their respective accounts of phenomenology. Heller (1990) adopts no-priority perdurantism in response to a phenomenological argument against perdurantism. Buonomo (2018) adopts wholes-first perdurantism in response to the same argument. In this section, I investigate the claim that different views on perdurantism and mereological priority reflect disagreements about the proper subjects of ordinary experience. This may be somewhat confusing because there is nothing inherent in this discussion of phenomenology that seems to directly entail that temporal parts or spacetime worms are more fundamental in an ontological sense. However, I frame things in this way because some parts-first, no-priority, and wholes-first perdurantists seem to adopt these positions in line with their views on mereological priority, rather than without reference to them. However, I argue that different views about priority ultimately fail to be probative here.

26 One might still object that these collected pluralities are just fusions in disguise. I don't discuss this issue, but Loss (2016) offers an interesting argument in response suggesting that we cannot treat fusions as identical to collected pluralities.

Roderick Chisholm argues that perdurantists cannot account for how human consciousness displays a kind of *unity* over time (Chisholm, 1971). When we hear an utterance of 'the sky is blue', we are experiencing the sentence in full. We might have this more sophisticated experience in virtue of multiple sub-experiences, such as hearing 'the', 'sky', 'is', 'blue' in succession.[27] Chisholm thinks that in order for us to experience 'the sky is blue', the entity having each part of that experience must be the self-same thing. The entity hearing 'the' must be the same as the entity hearing 'sky' in order for them to experience an utterance of 'the sky'. The thought here is that whenever we have an experience of some utterance like 'the sky is blue', we also have the second-order experience of 'the' and 'sky' being parts of the same experience. But under a perdurantist ontology that commits us to multiple entities experiencing each respective sub-experience, we have this second-order experience without any such genuine unity.

There are a few ways to respond to Chisholm. Heller (1990) responds by arguing that this argument only applies to parts-first perdurantism. Heller contends that parts-first perdurantism renders spacetime worms a 'mere convention' (Heller, 1990: 22). He thinks that if we take temporal parts as basic entities that compose perduring wholes, then we are forced to appeal to conventions as the thing which unite temporal parts. This seems like an odd claim to attribute to parts-first theorists. On my account, we can straightforwardly accept that spacetime worms aren't mere conventions and that some non-conventional things, such as parts, can ground other non-conventional things.

The 'conventionalism' of standard perdurantism is a kind of linguistic conventionalism, rather than a kind of conventionalism about existence. Consider the standard perdurantist response to paradoxes of coincidence and fission. In the case of the Ship of Theseus, a ship has a plank replaced after it is damaged (Sider, 2001a). Ships can survive the loss and replacement of a single plank. But suppose that each individual plank is slowly replaced over time. The old planks are kept in a warehouse and assembled into a new ship. Which ship is the same ship as the 'real' Ship of Theseus? There are clearly two salient spacetime worms which can serve as candidates: the 'replacement' worm and the 'old planks' worm. Which one gets to be called the Ship of Theseus is an issue of convention. Perhaps our concept of 'the Ship of Theseus' applies to the entity sailing back and forth from Crete to the Greek mainland or perhaps it is a convention that ships must retain their planks. Which entity is the 'real' Ship of Theseus is determined by linguistic convention. But both spacetime worms exist in the perdurantist's ontology, regardless of which one turns out to be the 'real' Ship of Theseus.

27 We could go even more fine-grained and talk about individual syllables.

Heller seems to think that parts-first perdurantism renders spacetime worms a mere convention because Chisholm derives his definition of temporal parts from the work of the 18th Century theologian Jonathan Edwards. Edwardsian temporal parts are instantaneous entities created *ex nihilo* by God (Helm, 1979). The Edwardsian view is a form of parts-first perdurantism where spacetime worms persist as a matter of (divine) convention. On Chisholm's conception of temporal parts, the religious aspects are unimportant. What matters for the view that Chisholm and Heller are discussing is that:

(1) Temporal parts are created *ex nihilo*.

(2) Temporal parts are more ontologically basic than spacetime worms.

(3) The existence of spacetime worms is merely a matter of convention.

Heller seems to take it that (1) and (2) imply (3). In rejecting the view that temporal parts come into existence *ex nihilo* and that they are more basic than their fusions, he argues that he can avoid Chisholm's objection.

The idea of temporal parts as entities created *ex nihilo* is significant here. Heller notes that this allows for degenerate cases where people experience a diachronic unity of consciousness. Let's consider the example of experiencing an utterance of 'evergreen'. We can divide this experience into two sub-experiences, the experience of hearing 'ever' and the experience of hearing 'green'. The experience of hearing 'green' immediately after hearing 'ever' is very different from the experience of hearing 'green' without this lead-in. We can call the first case an experience of 'green-1' and the second an experience of 'green-2.' The reason why these experiences are different is precisely because green-1 involves the retention of a specific earlier experience (hearing 'ever'), whereas green-2 does not.

It might be tempting to think of retaining the earlier experience of hearing 'ever' as a memory. However, there might degenerate cases where false memories can induce a kind of illusory unity.[28] Consider a case where someone experiences a green-1 experience without ever having heard an utterance of 'ever'. In this case, a person is created *ex nihilo* by God, is given the false memory of hearing 'ever', and then immediately hears an utterance of 'green'. This person's green-1 experience includes something which seems to them to be memory traces of hearing 'ever', even though they never actually had the experience of hearing 'ever'. Nonetheless, they would still have something which seems like the second-order experience of a unity of consciousness. This experience of a 'unity' of consciousness

28 There are more general issues with taking the retention required for diachronic unity to be memory. See (Brook and Raymont, 2017: §5).

does not require a single object to have both the 'ever' and 'green' experience, but this seems like a case where there is no such genuine unity.

In ordinary scenarios, we get into a green-1 experience through a causal relationship between our brain states at different times. We hear 'ever' at t_1 and 'green' at t_2. The state of my brain at t_2 is affected by the state of my brain at t_1. What matters is not that the entity experiencing green-1 is identical to the entity that initially heard 'ever', but that the entity experiencing green-1 is in the right causal relationship to experience a genuine unity of consciousness. One could easily replace this talk of 'my brain at t_1' and 'my brain at t_2' with talk of my brain's temporal parts. On this view, not all fusions are created equal. There is a genuine causal connection between my brain's temporal parts, whereas there is a far weaker causal connection between, say, my brain's temporal parts and yours. As Heller notes, perdurantists can give a genuine explanation of how an individual has a unity of consciousness that fares no worse than non-perdurantist explanations. Chisholm's argument only seems to succeed if all of our mental states must be fully intrinsic. It seems to presuppose that mental contents are internal, so that intrinsic duplicates must necessarily be in the same mental states. Such a strong assumption would need to be justified before it could present a serious objection to perdurantism. Even then, an internalist perdurantist could resist Chisholm's argument. They could claim that the unity of consciousness isn't merely about our mental states, but our mental states being caused in the right, non-degenerate way.

I reject Heller's claim that Chisholm's argument still succeeds against the parts-first perdurantist. Heller's objection to parts-first perdurantism is misguided. What he really seems to be objecting to is the Edwardsian conception of temporal parts and not parts-first perdurantism itself. Parts-first perdurantism does not entail that temporal parts are created *ex nihilo*, nor does it entail that ordinary objects are purely conventional. A parts-first perdurantist can help themselves to the same kind of explanation that Heller offers. So I don't think that perdurantists of any kind, aside from the Edwardsians, face any serious threat from Chisholm's argument. This also undercuts Buonomo's motivation for wholes-first perdurantism, which he argues is preferable because of its compatibility with the diachronic unity of consciousness (Buonomo, 2018).

Another phenomenological objection may concern the fact that all experiences take time. It might be fine to divide temporally extended experiences into smaller chunks, but can we really divide them into temporal instants? Presumably desiring, experiencing, and thinking all take more than an instant to obtain. So instantaneous person-stages cannot be the subjects of first-person experience.

There are two good replies to this objection. The first is to point out that perdurantism does not require a commitment to the view that all temporal parts are instantaneous. We could have extended temporal parts, which are extended in time for a few seconds, or at least longer than a single instant. Alternatively, we could use the same kind of reply that Heller offers against Chisholm to deal with this objection too. The property of having a temporally extended experience could be a relational one. Either way, parts-first and no-priority perdurantists can avoid this objection with relative ease.

The phenomenology of action also motivates this tension between part and whole. People tend to have a special concern for their future, they deliberate and act for their future selves. I am willing to spend time writing my thesis in the present, instead of doing other things, because I believe that this will benefit me in the future. Some suggest that this only makes sense if our future-regarding thoughts and actions are being had by the self-same person. If the subject of my experience is a temporal part because my experience is grounded in my temporal parts, then we are making sacrifices for our distinct temporal parts in the future. In contrast, Buonomo's wholes-first pedurantism has an easier time accounting for this intuition.

These phenomenological considerations cut both ways, however. Parsons offers what he calls a phenomenological argument for the stage theory (Parsons, 2015).[29] He argues that the stage theory offers the best account of how and why our conscious experience is of the present. What I am experiencing, right now, is not my entire life. I am experiencing a single time, whether it's an instant or a time with a reasonably short duration. The real locus of temporal experience is the person-stage, not the spacetime worm.

Parsons goes one step further: he claims that our phenomenology privileges the present to such an extent that things in the present and the near past seem more real to us than things in the distant past and future. The stage theorist has an easy explanation for this: people are person-stages located at a single time. Things located in your distant past and distant future don't seem as real to you because you're not experiencing them. You are a short-lived entity experiencing a short moment in the history of your life.

In contrast, Parsons contends that the worm theorist cannot provide a satisfactory explanation of why the present and near past are privileged in our phenomenology. But why? The parts-first worm theorist also has a fairly simple explanation. You are a temporally-extended entity that

29 Bradford Skow (2011) offers a similar argument, although his differs in that it is a deductive argument, whereas Parsons's is an abductive one. Skow also provides different responses to objections.

changes over time and you experience things in virtue of your temporal parts. What you experience also changes over time. You experience some time t_1 because you have a temporal part located at t_1, then you experience t_2 because you have a temporal part located at t_2, and so on. This doesn't mean that what you're experiencing right now is somehow more 'yours' than what you experienced yesterday. Our phenomenology might privilege certain times, but our metaphysics doesn't.

Parsons considers this objection and offers what he admits is a flat-footed reply. It simply seems to him that we really are person-stages and that's why what we're experiencing right now seems privileged over temporally distant things. If you reply, 'No, it really seems to me that I am a spacetime worm!', then Parsons admits that there is little he can do to change your mind. Parsons's own phenomenological introspection is hardly a strong point against the worm theory.

One might still contend that the stage theory still wins out in the end because it provides a simpler account of our temporal phenomenology and the indexical 'I'. The thought here might be that on the stage theory, my present experience is had by me *simpliciter* whereas it is not on the worm theory. If I am a spacetime worm, then my present experience is understood as a relation to a temporal part that has the experience *simpliciter*.[30] This is a fairly standard point in favour of the stage theory. It is, however, offset by the problems that the stage theory runs into when dealing with properties that require temporal extent (Haslanger, 2003: 334). For example, I only 'persist' because I stand in the right temporal counterpart relation to other stages on the stage theory. Furthermore, I have previously argued that the stage theory ultimately provides an inferior semantics to the worm theory in Counting for Worm Theorists. As such, I see no compelling reason to adopt the stage theory over the worm theory.

What I do see in Parsons's argument could be a reason to reject Buonomo's version of wholes-first perdurantism. My thinking, experiencing, and desiring is being done by my temporal parts. In other words, I experience the world in virtue of my temporal parts. Perhaps no-priority perdurantism is amenable to this view, particularly if it turns out that this debate has little to bear on the broader question of whether to take temporal parts or spacetime worms as basic. Buonomo's view is in trouble, however. In his version of wholes-first perdurantism, spacetime worms are the real site of experience, thought, and action (Buonomo, 2018: 108). Yet, as Parsons's argument shows, our first-person experience seems to be in virtue of our temporal parts. Here the wholes-first perdurantist has a few options. The first would be to argue that our phenomenology is illu-

30 Skow (2011) finds this claim difficult to believe. He suggests that we can only be confident that our experiences are had *simpliciter* by anything if we are confident that they are had by us. I don't see any strong reason to motivate this worry.

sory. Parsons considers this option but ultimately dismisses it, noting that it seems to posit a plenitude of similar illusions at each moment we exist where one of the illusions (the one located in the specious present) seems to be the most vivid (Parsons, 2015). Another option would be to reject Parsons's account of our phenomenology. Perhaps he and I are both mistaken, and we don't really have this phenomenology. I don't find this reply particularly compelling, at least not without a new argument for rejecting this account of first-person experience.

Our phenomenology seems to pull us in different directions. It's not clear that parts-first, no-priority, or wholes-first perdurantism win out based on phenomenological concerns alone. They might not actually be relevant to these debates over phenomenology at all. Firstly, it's not unreasonable to assume that a successful explanation of experience is ultimately going to be a causal, physical one. Our phenomenology may not, one might think that it probably will not, be explained with grounding. Especially considering that these debates concern the nature of what and how we experience more so than they do the grounds of experience.

Secondly, it's not at all clear that priority tells us anything about what entity is the subject of ordinary first-person experience. Why should we think that parts-first perdurantism entails or even implies that temporal parts are at the centre of our phenomenology? Experience and fundamentality do not run in parallel to each other. We wouldn't be justified in claiming that elementary particles are experiencing subjects instead of human brains because they are more fundamental than them, for example. Suppose that, for the sake of argument, phenomenological arguments successfully demonstrate that the temporal parts of my mental states are prior to their fusions. Even then, this would still not demonstrate that the temporal parts of me are prior to my fusion. We would need some additional argument or bridge principle to explain how the priority of my mental state's temporal parts generalises out to all of my other temporal parts. It is for these reasons that, unlike Buonomo and Heller, I do not find priority to be particularly illuminating here. However, there is a different scenario where I do think that perdurantists need to take a stand on the issue of priority. This is a scenario concerning Minkowski spacetime.

3.6 MINKOWSKI SPACETIME

On the special theory of relativity, ordinary objects are appear to have different three-dimensional shapes from different (inertial) frames of reference. Many people, particularly perdurantists, think that there is something invariant which unifies these many three-dimensional shapes. They believe that this is a four-dimensional world tube. When we look at an ob-

ject's four-dimensional world tube from different frames of reference, we see its many different three-dimensional shapes. These three-dimensional shapes are perspectival representations of the four-dimensional world tube. This follows from the more basic fact that frames of reference are essentially conventional ways of representing four-dimensional Minkowski spacetime.

Perdurantists are well-equipped to rise to the demands of special relativity. They can, following Yuri Balashov, hold that ordinary objects exactly occupy a unique four-dimensional region in spacetime – their world tube (Balashov, 2010). For each overlapping region between an object's four-dimensional world tube and some frame relative time from some frame of reference, the object has a temporal part that is exactly located at that region.

Unfortunately, this special relativity-friendly account is not available to temporal parts-first perdurantists. The reason for this is simple: if times are sets of simultaneous events, then (instantaneous) temporal parts are not relativistically invariant and four-dimensional volumes are.[31] If temporal parts are not relativistically invariant, then they cannot be more fundamental than their invariant wholes. Temporal parts cannot be relativistically invariant because times are not prior to spacetime regions in Minkowski spacetime.

For an object O's temporal parts to be prior to O, there would need to be some metaphysically privileged frame of reference where the achronal regions occupied by O are all exactly occupied by O's temporal parts and not, say, strange hybrids of temporal parts. However, there is no such privileged frame in Minkowski spacetime.[32] As Gibson and Pooley point out:

> From the physicist's perspective, the content of spacetime is as it is. One can choose to describe this content from the perspective of a particular inertial frame of reference (i.e., to describe it relative to some standard of rest and some standard of distant simultaneity that are optimally adapted to the geometry of spacetime but are otherwise arbitrary). But one can equally choose to describe the contents of spacetime with respect to some frame that is not so optimally adapted to the geometric structure of spacetime, or indeed, choose to describe it in some entirely frame-independent manner. (Gibson and Pooley, 2006: 162)

Hence, O's temporal parts cannot be prior to O. What is relativistically invariant, and thus has some chance of being fundamental, is the spacetime region occupied by the whole of O.

31 Davidson (2014) argues against the relativistic invariance of four-dimensional shapes. Balashov (2014) replies and Calosi (2015) offers an independent argument in support of invariance.

32 This argument from simultaneity has also been used to argue against the A-theory of time and presentism (Putnam, 1967).

Alternatively, we could take time to be a 'flat' *Cauchy* surface. A Cauchy surface is a three-dimensional spacelike region extending throughout the entirety of space. Steven F. Savitt defines Cauchy surfaces as a set of achronal spacetime points such that every single timelike and lightlike curve without end intersects it exactly once (Savitt, 2000: S571). A Cauchy surface is 'flat' if there exists some frame of reference where all of its constituent spacetime points are mutually simultaneous (Gilmore, Costa, and Calosi, 2016: 116). On this view, 'being a time' is invariant and so too is the notion of being a temporal part. But this view also leaves us with a plenitude of temporal parts, all massively overlapping each other. It's very difficult to see how such things jointly ground in an explanatorily useful way, given the massive redundancy of information on offer. Furthermore, this 'flat' Cauchy surface picture is not an attractive option for standard B-theoretic perdurantists. The idea that time is a 'flat' Cauchy surface is generally proposed as a way to make special relativity more friendly to A-theorists, since it allows times to be relativistically invariant (Gilmore, Costa, and Calosi, 2016).

Another argument by Yuri Balashov (2000; 2010), which purports to demonstrate an advantage perdurantism has over endurantism, could also be modified to be an argument for wholes-first perdurantism:

(1) In a relativistic setting, individual objects have many different three-dimensional shapes in different reference frames.

(2) *(Wholes-first)* Perdurantism can show how these different shapes are related: They are mere perspectival representations of a smooth four-dimensional volume which 'stands behind' them.[33]

(3) Endurantists *(and parts-first perdurantists)* are unable to adequately explain how collections of three-dimensional shapes 'come together in a remarkable unity'.

(4) Ergo, *(wholes-first)* perdurantism offers a superior explanation of this phenomena. (1, 2, 3)

(5) All other things being equal, the theory that provides the better explanation is more likely to be true. (Inference to the Best Explanation)

(6) *(Wholes-first)* Perdurantism is more likely to be true. (4, 5)[34]

Balashov claims that his version of this argument, which makes no distinction between parts-first and wholes-first perdurantism, has nothing to do with grounding or metaphysical dependence. Perdurantists are able

33 The same would apply for transdurantism.

34 The italicised text is added by me and not present in Balashov's argument. In addition, my presentation of this argument in premise-conclusion form is borrowed from (Eagle, 2011).

to explain how a single object appears to have different three-dimensional shapes in different frames of reference by highlighting how these shapes are simply different frame dependent slices of a four-dimensional object. It's a useful explanation, but not a metaphysical one. He goes as far as to make it clear that he believes 'the facts about the occupation of space-time points by fundamental particles, along with the facts about composition at-a-time in-a-frame, ground the facts about 3D shapes' (Balashov, 2000: 213). Nonetheless, I think that there are good reasons to treat this as a metaphysical argument for wholes-first perdurantism.

Balashov writes about how four-dimensional objects 'stand behind' their three-dimensional parts, which are just entities "carved out' from [their whole]' (Balashov, 2000; 2010). This seems to imply that Balashov's explanation is a metaphysical one where four-dimensional wholes are prior to their three-dimensional parts.

Another reason is that the argument, if non-metaphysical, is a very low stakes one. Endurantists have a few different avenues for explaining how different three-dimensional shapes are related to each other and fit into a four-dimensional volume. The transdurantist can help themselves to the same kind of explanation that Balashov uses, whereas endurantists that endorse multi-location can follow Sider's strategy of grounding an object's four-dimensional path in the location of its constituent fundamental particles (Sider, 2001a: 83).[35] Balashov contends that his explanation is better than Sider's at a macroscopic level since he has a fairly simple explanation that doesn't rely on various facts about micro-level objects and their locations. Even so, Balashov's commitment to the primacy of facts about fundamental particles and composition means that his 'macroscopic' explanation would still bottom out in much the same way as Sider's does. If the argument is merely that perdurantists and transdurantists can give a slightly more convenient macroscopic explanation than multi-location endurantists, then it does not seem to matter a whole lot whether Balashov is right or wrong. Perdurantists and transdurantists gain very little, while multi-location endurantists don't lose much either.

If, on the other hand, we treat this as an argument for wholes-first perdurantism, then the stakes are much higher. The wholes-first perdurantist and the transdurantist have a tidy explanation of why collections of three-dimensional shapes are unified in four dimensions. The four-dimensional whole is fundamental and its three-dimensional parts are mere perspectival projections of it. Balashov's macroscopic explanation would turn out to be irreducible to facts about fundamental particles occupying point-sized regions of spacetime. Ultimately, I think that this is the most natu-

35 Gibson and Pooley (2006) and Miller (2004) also develop an endurantist account in response to Balashov.

ral way to make sense of a four-dimensional entity 'standing behind' its parts. And, if the argument succeeds, then endurantists and parts-first perdurantists have an inferior metaphysical explanation.

Unfortunately for wholes-first perdurantists, I don't think the argument is successful. Parts-first perdurantists have a principled way to explain the phenomenon at hand. They can explain the four-dimensional path of an object in terms of the trajectories of their constituent particles. Then, we can associate that four-dimensional path with a single entity. This gives parts-first perdurantists access to the same kind of explanation that Balashov offers: many different-looking three-dimensional shapes are neatly related because they are just the shapes of a four-dimensional volume occupied by a single object.[36]

But what about the initial argument from simultaneity against the priority of temporal parts? I suggest that the parts-first perdurantist follow Gibson and Pooley (2006) in thinking in terms of *spatiotemporal parts* in a relativistic setting. The distinction between spatial and temporal parts is valuable in ordinary metaphysics, but not in relativity theory. Space and time are unified, so what looks like temporal change from one perspective looks like spatial variation from a different one (Hawley, 2009: 512). Something which is a temporal part from one frame of referecne is not from another and the same goes for spatial parts. On this picture, four-dimensional objects are composed of many point-sized spatiotemporal parts for each point-sized subregion of the whole region that they occupy. Spatiotemporal parts are prior to spatiotemporal wholes for the same sort of reasons that we think purely temporal parts are prior to purely temporal wholes.[37]

This means abandoning temporal parts-first perdurantism in favour of spatiotemporal parts-first perdurantism. Earlier, I claimed that wholes-first perdurantism risks collapsing into a form of endurantism, but does spatiotemporal parts-first perdurantism have the same problem? One might argue that spatiotemporal parts, unlike temporal parts, can be endorsed by endurantists. Any substantivalist who believes that spacetime is a substance and believes that spacetime can be divided into parts presumably accepts 'spatiotemporal parts' too. This may be true, but what matters is not whether spatiotemporal parts or temporal parts are permitted in one's ontology but what they *do*. For the transdurantist, spacetime may have spatiotemporal parts, but ordinary objects are extended simples. Likewise, the multi-location endurantist might believe in spatiotemporal parts but still believes that ordinary objects are simples with multiple exact locations. In contrast, the spatiotemporal-parts first perdurantist believes

36 My reply is similar to Eagle's (2011) response on behalf of the endurantist.
37 In addition to the reasons that we might take parts to be prior to wholes in general.

that ordinary objects have one unique location: the extended spacetime region filled up by its spatiotemporal parts.

Furthermore, spatiotemporal parts ought to be understood as unifying the classical notions of spatial and temporal parts in much the same way that Minkowski spacetime is best understood as unifying the spatial dimensions and the time dimension. Temporal parts and spatial parts are still part of the picture, they just aren't the kind of things that can be fundamental.

This view also vindicates the common perdurantist claim that extension through space and extension through time are much alike. It's a natural fit with the standard perdurantist package which comes along with a B-theory of time and eternalism. Spatiotemporal parts-first perdurantism allows us to keep the more general advantages of parts-first perdurantism here without falling prey to the flaws of wholes-first perdurantism.

3.7 CONCLUSION

I have outlined parts-first, no-priority, and wholes-first forms of perdurantism. Parts-first perdurantism seems to be the canonical form of perdurantism and seems to fit with our intuitions about part-whole relations. Parts-first and wholes-first perdurantism are not seriously threatened by concerns about the intimacy and innocence of mereology or strict composition as identity. As such, I see little reason to endorse no-priority perdurantism. Wholes-first perdurantism may sound the most strange out of the three, but there are a number of different ways to make it a palatable view. Furthermore, those convinced by some of the arguments for priority monism ought to be wholes-first perdurantists. The relevance of priority, according to Buonomo and Heller, is in how it can be used to respond to phenomenological arguments. However, as I have argued, there are good reasons to believe that phenomenological arguments favour no particular view here. Instead, priority matters because of the arguments I present from Minkowski spacetime, which put pressure on perdurantists to choose between parts-first and wholes-first perdurantism.

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4

How (Quantum) Things Persist

4.1 INTRODUCTION

In this paper, I explore the issue of how quantum objects persist through time. In particular, I evaluate some recent arguments made by Thomas Pashby regarding the implications that quantum theory has for metaphysical debates regarding persistence (Pashby, 2013; 2016). Before doing this, I will provide a brief overview of the persistence debate more generally.

Broadly speaking, the debate over how objects persist centres around two views. The first is endurantism, which is the view that objects are *wholly* present at each moment of their existence. In contrast, perdurantists believe that objects persist by having temporal parts at different times of their careers. The doctrine of temporal parts suggests that objects are, in some sense, only partly present at any one temporal instant. This debate hinges on whether objects have temporal parts.

However, the metaphysics of persistence has recently undergone what Damiano Costa calls the *locative turn*. (Costa, 2017: 57) In addition to the disagreement over mereology, the persistence debate also encompasses a debate concerning locations. *Locative* endurantists hold that objects have many exact locations at many spacetime regions. If we take these objects to be multiply 'wholly located' at every moment at which they exist then this is an endurantist view. So, this is a view which can capture the endurantist notion of being 'wholly present' and explain persistence without invoking temporal parts. Locative endurantism provides the resources to say that objects are *wholly present* at each region they exactly occupy. While the locative endurantist thinks that objects are exactly located many times over, so-called locative perdurantists contend that objects only have one exact location: their *path*. The path of an object is the fusion of all of its exact locations. In other words, the path of an object is the region where its entire career is exactly located. An object is *exactly located* at some region *iff* it has the exact same shape and size as that region and stands in all the same spatiotemporal relations to entities as that region (Gilmore, 2008: §2).

One can have a mereologically endurantist but locatively perdurantist metaphysics. In this view, persisting objects are singly located at their respective paths but they do not have temporal parts. This view is known as *transdurantism*. Mereological forms of endurantism do not seem to

entail their locative siblings and the same goes for perdurantism.[1] Mereological theories of persistence were developed to deal with the problem of change, whereas locative theories concern debates about the metaphysics of location.

In 'Do Quantum Objects Have Temporal Parts?', Pashby develops a notion of quantum temporal parts which he argues is incompatible with quantum theory (Pashby, 2013). In 'How Do Things Persist? Location Relations in Physics and the Metaphysics of Persistence', he argues that some other formulations of perdurantism in quantum mechanics also fail (Pashby, 2016). What Pashby offers are some novel arguments which attempt to apply quantum theory to the metaphysics of persistence.

Why should metaphysicians take arguments from quantum theory seriously? Well, quantum mechanics is a purportedly fundamental theory of matter. Along with general relativity, quantum mechanical theory is one of the two major pillars of modern physics. Many philosophers rightly have serious issues with contravening contemporary physics. Presumably, we all want to keep our metaphysics consistent with things that we take to be true. As such, we should reject accounts of persistence that are at odds with fundamental physics.

The structure of this paper is as follows. In §4.2, I begin by introducing Pashby's main assumptions and the Hilbert space formalism that he uses. Then, I outline Pashby's first argument against perdurantism in §4.3. I will turn in §4.4 to Pashby's second argument against perdurantism, which demonstrates a problem with Wightman localisation that puts pressure on Pashby to adopt an event ontology of quantum 'objects' and a theory of persistence that he calls *reiterationism*. In §4.4, I investigate Pashby's reiterationism and argue that it is actually a form of perdurantism with additional assumptions. Finally, I argue that we have good reasons to reject some of Pashby's more controversial assumptions and that perdurantists can develop a quantum mechanics-friendly theory by doing so. Ultimately, I contend that perdurantists have no need to radically revise their metaphysics in light of Pashby's arguments.

4.2 PASHBY'S FORMALISM

The specific formalism and interpretation of quantum theory that we ought to adopt remains up for debate. It is necessary to take sides when evaluating arguments that apply results from a particular formalism to meta-

1 One could also have a mereologically perdurantist but locatively endurantist metaphysics. Persisting objects turn out to be multi-located things with temporal parts for each of its instantaneous exact locations. Hudson (2001) endorses a view somewhat similar to this, where objects are located at many different overlapping four-dimensional regions.

physics. This is because different interpretations of quantum theory entail different views about fundamental ontology.

Pashby notes that his arguments rely on two key assumptions (Pashby, 2013). The first is *realism*, which is simply the claim that quantum states provide an accurate description of the physical systems. This also includes the forward implication of the eigenstate-eigenvalue link. Briefly put, this is the claim that iff a physical system is in an eigenstate of an observable then we can assign it an eigenvalue and that when physicists measure an eigenvalue of an observable's operator then that system is in an eigenstate. If a physical system is not in an eigenstate, then it we cannot assign it an eigenvalue. In other words, a system in some state $|\psi\rangle$ has a eigenvalue o_i iff $|\psi\rangle$ is an eigenstate of $\hat{O}$.[2] The second is *completeness*, which is the claim that a pure state gives us a complete description of an individual quantum system.[3] Nothing is left out and there are no hidden variables, like those postulated by Bohmian interpretations of quantum mechanics. Hence, the assumption of completeness rules out Bohmian mechanics.[4]

We could choose to take completeness for granted. One might note that it would be unreasonable to expect philosophers of science to defend their interpretation of quantum mechanics every time they make an argument. That Pashby's metaphysical conclusions are derived from a specific interpretation of quantum mechanics precludes a strong result.[5] Pashby defends the assumption of completeness on the basis that it, combined with the rest of his formalism, has a solid claim to be the 'canonical form of quantum mechanics'. Assuming completeness puts pressure on Pashby to adopt an interpretation of quantum mechanics that secures it, such as a Copenhagen interpretation or the Everettian interpretation.

Pashby goes on to suggest that his assumptions justify the claim that quantum states describe real physical objects. Pashby argues that metaphysicians who are realists about ordinary objects ought to treat quantum states as describing persisting objects. He points to the fact that even large molecules like buckminsterfullerene (C_{60}), also known as 'buckyballs', exhibit quantum behaviour. As such, he suggests that those who believe that tables (composed of collections of complex molecules) are persisting objects ought to believe that buckminsterfullerene molecules are too. He then goes on to claim that states describe *persisting* physical objects.

Pashby's arguments deal with systems that have no internal degrees of freedom like spinless particles. The state space $\mathcal{H}$ of quantum theory is

2 We can take the eigenvalue o_i to be an associated definite value O.

3 This assumption is a kind of synchronic completeness, since a truly complete description should also tell us about quantum dynamics.

4 Also known as the De Brogile-Bohm theory.

5 This is hardly a serious issue given that the different responses to the measurement problem tend to entail different metaphysical conclusions.

provided by the space of quadratically-integrable functions which are defined over the entirety of space.[6] Or rather, the space of quadratically-integrable functions defined over infinite-dimensional complex Hilbert space $\mathcal{H} = L^2(\mathbb{R}^3)$.[7] By 'complex', I mean that infinite-dimensional Hilbert space is taken over the complex numbers. Pure states $|\psi\rangle$ are in a one-to-one correspondence with the one-dimensional subspaces of $\mathcal{H}$, or more specifically, the set of independent unit vectors that individually span those one-dimensional subspaces. The superposition principle tells us that linear combinations of pure states can also be given as pure states, since $\mathcal{H}$ is a vector space.

To see how quantum states could describe persisting objects, we need to look at the Schrödinger and Heisenberg pictures of quantum mechanics. In the Schrödinger picture, the operators are constant and the state vectors evolve over time. The opposite is the case in the Heisenberg picture: the state vectors are time-independent while the operators that act on them vary over time.

In the Schrödinger picture, the persisting quantum object is described by a family of states $|\psi(t)\rangle$, which are parameterised by $t \in \mathbb{R}$. After the state of a system at a time is given, the whole family of states is determined in accordance with the time-dependent Schrödinger equation: $|\psi(t)\rangle = U_t|\psi(0)\rangle$. The pure state $|\psi(0)\rangle$ describes an object that exists at time $t = 0$. We can then interpret the family of states $|\psi(t)\rangle$ as describing a persisting object that exists at each time t. In the Heisenberg picture, the state of the system is $|\psi\rangle$ at all times, whereas the operators evolve with time.

However, must we take the Schrödinger picture states $|\psi(t)\rangle$ to describe a persisting object? Presumably, things can go out of existence in the quantum system and that will be captured in the time evolution of the system too. Hence, it might be more appropriate for us to consider $|\psi(t)\rangle$ as describing a persisting process or a system of transient things. This view has received support in both the foundations of physics literature and in Mauro Dorato's work on the ontology of quantum mechanics.[8] We don't denote quantum systems using the natural language predicate 'is an object' and it's not clear that *all* quantum systems are objects in a metaphysical sense either, although some might be. Some have even argued that quantum systems cannot be individuals (da Costa and Lombardi, 2014). I will put this worry aside for now and return to it later.

The Schrödinger and Heisenberg pictures are equivalent in the sense that they give the same expectation values for any operator. Pashby ar-

6 For the sake of simplicity, I'm only considering a single spatial dimension.

7 To account for an additional internal degree of freedom with two possible values, the state space for particles with spin is $\mathcal{H}_e = L^2(\mathbb{R}^3) \otimes \mathbb{C}^2 = L^2(\mathbb{R}^3\mathbb{C}^2)$.

8 See (Dieks, 2002; Haag, 2013; Rovelli, 2005) for physicists and (Dorato, 2015) for a philosopher.

gues, however, that the two pictures might not be metaphysically equivalent. This brings us to Pashby's evaluation of mereological theories of persistence.

4.3 QUANTUM MEREOLOGY

In Pashby's view, the family of states $|\psi(t)\rangle$ can suitably describe a number of short-lived, instantaneous objects, while $|\psi\rangle$ can more easily be conceived of as a temporally extended individual. According to him, the Schrödinger picture states $|\psi(t)\rangle$ fit best with endurantism and the stage theory. His endurantist interpretation of the Schrödinger interpretation suggests that the states $|\psi(t)\rangle$ are distinct states of a single, persisting individual. Admittedly, it is hard to see how intuitively this fits with endurantism. If $|\psi\rangle$ describes a single individual that exists at many times, then we have some *prima facie* reason to hold that the Heisenberg picture is actually a better fit for endurantism. Presumably, Pashby thinks that the Schrödinger picture works well for endurantists because endurantists want a picture where things have many three-dimensional locations.[9] In his account, the Schrödinger picture is one where an object is wholly as it is at each time, and it changes as its state evolves. Note, however, that this change is precisely what motivates perdurantist solutions to the problem of change in the first place. In contrast, Pashby thinks that the Heisenberg picture works well for perdurantists and transdurantists because those theories entail that objects have a single four-dimensional location. A time-independent state vector which 'looks different' at different times once the operators that act on them evolve seems to fit with this.

Pashby notes that the Schrödinger picture states $|\psi(t)\rangle$ seem to fit well with the stage theory, which is a heterodox form of perdurantism that takes temporal parts themselves to be continuants and not spacetime worms.[10] We could take it that these states correspond to a series of distinct, instantaneous quantum objects related by the non-periodic unitary group Ut. We could then take temporal parts of a persisting quantum object to be sets of these states. The set of states $\{|\psi(t)\rangle : t \in [t_1, t_2]\}$ describes a series of instantaneous stages which collectively extend from t_1 to t_2. Oddly, Pashby seems to implicitly rule this view out for worm-theoretic perdurantists. As previously noted, he claims that worm theorists and transdurantists must describe objects using the Heisenberg picture state $|\psi\rangle$. This is odd because worm theorists and stage theorists share the same funda-

9 Even so, it's not at all clear that the Schrödinger picture can supply us with three-dimensional locations. We could end up without any well-defined positions at all over the evolution of the system.

10 The stage theory is also called 'exdurantism' (Haslanger, 2003).

mental ontology. The key distinction between the two views is that worm theorists claim that the objects we discuss and quantify over are spacetime worms while stage theorists claim that these objects are temporal stages. However, most stage theorists also accept spacetime worms exist. Worm theorists and stage theorists share an ontology, so the key difference between them is in their philosophical semantics.[11] If stage theorists are able to account for arbitrary instantaneous quantum objects, then there is no reason to think that worm theorists cannot do the same. The objects of quantum theory are not typically members of any ordinary sortal predicate to begin with, so linguistic disagreement about ordinary sortals shouldn't have any impact here. Even so, whether we treat the sortal 'electron' in a worm-theoretic or stage-theoretic way is unlikely to make any difference serious enough to force us to adopt a particular picture of the dynamics.

So I disagree with Pashby that the mathematically equivalent Schrödinger and Heisenberg pictures of quantum mechanics are not metaphysically equivalent. Both pictures can represent perdurantist and endurantist metaphysics. The mathematical equivalence of the two pictures opens the door to metaphysical equivalence. If any particular theory of persistence were ruled out in one picture, I would think that it would be ruled out in the other.

For perdurantism, the Schrödinger picture seems to be a good option for developing an account of temporal parts. Nevertheless, Pashby's view that worm theorists are forced to adopt the Heisenberg picture motivates the rest of his argument. While he does not consider relativistic quantum mechanics in his paper, he notes that it poses some problems for the Schrödinger picture (Pashby, 2013: 1147). Assuming we have independent reasons to adopt the Heisenberg picture, it is worth developing a Heisenberg-friendly account of quantum temporal parts.

What does it mean to say that the Heisenberg picture state $|\psi\rangle$ has temporal parts? Pashby suggests that we can discover a notion of what it is for $|\psi\rangle$ to have temporal parts by revisiting Lewis's original motivation for perdurantism. That is, by drawing an analogy between temporal parts and spatial parts. Just as ordinary objects extend through space by having parts at different spatial locations, they also extend through time by having temporal parts at different times. So, Pashby takes it that an appropriate idea of what it is for $|\psi\rangle$ to have temporal parts ought to be similar to an appropriate account of how we might say it has spatial parts.

Pashby thinks that we need some way to describe $|\psi\rangle$ as a sum of quantum objects with a suitable part-whole relation. Recall that Pashby is as-

11 Excluding nihilist stage theorists or *pixelists*, who do not believe that temporal parts fuse into spacetime worms (Patrone, 2020).

suming completeness here, so it makes sense that we need something in the permanent state description to correspond to a description of the actual object's spatial and temporal parts. The most direct way to do this is to find a way to talk about the state as a sum of quantum objects.[12] Part-whole relations in standard mereology are reflexive, transitive, and antisymmetric. Pashby notes that the subspaces of a vector space labelled $A, B, C \ldots$ are partially ordered by an inclusion relation. This relation is reflexive because $A \subseteq A$. It is transitive because if $A \subseteq B$ and $B \subseteq C$, then $A \subseteq C$. It is also anti-symmetric because if $A \subseteq B$ and $B \subseteq A$ then $A = B$.

Pashby suggests that we can develop a notion of quantum spatial parts in reference to a *localisation scheme*. Essentially, we can give the spatial parts of $|\psi\rangle$ in terms of the subspaces of $\mathbb{H}$ that are associated with the eigendecomposition of the position observable Q of a particle. The position observable Q plays a useful role in Pashby's account because it links every spatial region $\triangle$ with a projection operator $P_\triangle$ on $\mathbb{H}$ in such a way that disjoint spatial regions are assigned to mutually orthogonal subspaces.[13] When we project a vector state $|\psi\rangle$ onto the subspace that is associated with $\triangle$, we get the state $P_\triangle|\psi\rangle = |\psi_\triangle\rangle$. Pashby notes that we can take $P_\triangle|\psi\rangle = |\psi_\triangle\rangle$ to describe a quantum object wholly located within the region $\triangle$ which is a spatial part of $|\psi\rangle$. The spatial part $|\psi_\triangle\rangle$ is wholly located within $\triangle$ because it is the eigenstate of $P_\triangle$, which is a projection valued measure (PVM) that associates spatial regions with subspaces of $\mathbb{H}$.[14]

One problem with Pashby's scheme is that we need not interpret it as something providing us with spatial parts. We could alternatively take $P_\triangle|\psi\rangle = |\psi_\triangle\rangle$ to be something that is true of $|\psi\rangle$ relative to $\triangle$. In other words, $P_\triangle|\psi\rangle = |\psi_\triangle\rangle$ describes $|\psi\rangle$ from the perspective of $\triangle$. So it could include properties $|\psi\rangle$ has at $\triangle$ by virtue of other locations. For example, locative endurantists might want to say that someone currently sitting down has the property *was standing*.[15]

But one advantage of this way of assigning spatial parts is that they *covary* with *spatial translations*. Spatial translation is when we apply a *translation operator* which shifts particles in a specific direction by a spe-

12 Of course, there may be other ways of doing this. But if we're assuming completeness, then we need something in the state description to correspond to a description of the object's parts.

13 It's important to note as well that subsystems only correspond to independent spatial parts if they are associated with mutually orthogonal projections. Otherwise this scheme would fail to respect the phenomenon of *entanglement*.

14 Obviously the localisation scheme itself doesn't tell us anything about where systems are localised in particular but merely that they *localisable*. In general, systems will not be in an eigenstate of any projection $P_\triangle$.

15 They have that property while they are sitting.

cific amount. These spatial parts covary with spatial translations because $U_a^\dagger P_\triangle U_a = P_{\triangle - a}$, where $U_a = e^{-iPa}$ is the single parameter group of spatial translations in the direction of a which is generated by the momentum P. This is due to the fact that the position observable Q and P are canonically conjugate, as $[Q, P] = i$. We can view these translations as passively moving the origin of the spatial coordinates by a. In the new coordinates, $P_{\triangle - a}|\psi\rangle$ denotes the same spatial part that $P_\triangle|\psi\rangle = |\psi_\triangle\rangle$ does in the old coordinates. If we view this actively, then the covariance ensures that the part $U_a|\psi_\triangle\rangle$ is simply the same part $|\psi_\triangle\rangle$ moved to a new position $\triangle + a$.

However, in the Heisenberg picture, the projections $P_\triangle(t)$ are indexed to times. We end up with $P_\triangle(t)|\psi_\triangle\rangle = U_t^\dagger P_\triangle U_t = |\psi_\triangle\rangle$. Here, the subspaces picked out by the Heisenberg picture projections are invariant under temporal translations.

Put simply, all of this means that if we were to apply a translation operator to a system, measure its position, and then translate it back, then we would get the same result as if we had just measured its position directly in the first place.

One might object that Pashby is assuming we must define our mereology in terms of quantum mechanics.[16] It might be beneficial to define spatial parts directly in terms of spatial regions, but it is unclear that we should begin our theory of parthood with quantum mechanics. Even then, those who consider mereology an extension of first-order logic may be inclined to suggest that we should not define parthood in terms of quantum mechanics in the same way that we should not define the existential quantifier in terms of quantum mechanics. One might instead be attracted to the idea that we take parthood as basic and then work out which parts are spatial or temporal once we figure out where they are located. Pashby (2016) points out that since localisation schemes in quantum mechanics make no references to spatial parts, we might be better off treating quantum systems as extended simples.[17] Pashby has essentially gerrymandered a notion of spatial parthood out of a localisation scheme that doesn't entail parts. Nevertheless, I will continue.

By analogy to his notion of quantum spatial parthood, Pashby suggests that a temporal part present during the interval $I = [t_1, t_2]$ is a quantum object $P_I|\psi_I\rangle$ which is a part of $|\psi\rangle$. Presumably, the temporal parts of $|\psi\rangle$ would be objects $|\psi_I\rangle$ which are eigenstates of a projection associated with the interval I. This projection, P_I, is a PVM. This way, the subspaces associated with disjoint intervals are mutually orthogonal and $|\psi_I\rangle$ is only present at I.

16 This is particularly problematic when we consider the prevalence of *quantum holism*: the thesis that the properties of a quantum system do not supervene on those of its parts.

17 Extended simples are also called 'spanners' (McDaniel, 2007).

Pashby's main worry for this notion of temporal parts is that it must adhere to *temporal translation* invariance, just as his notion of spatial parts adheres to spatial translation invariance. A temporal part $|\psi_I\rangle$, when shifted in relative time by t via the application of a translation operator, should be identical with the temporal part wholly present during $I + t$. Here P_I needs to covary with the time shift such that $U^\dagger P_I U_t = P_{I-t}$. This is because, as Pashby notes, that our definition of temporal parts should not rely on any particular coordinisation of the time axis. A temporal part wholly present during I, when 'shifted' in relative time by t, ought to be identical with the part wholly present during $I + t$. While spatial translations are generated by the self-adjoint momentum operator P (canonically conjugate to H), temporal translations must be generated by the self-adjoint time operator T (also canonically conjugate to H). On this scheme, temporal parts exist in virtue of the properties of a general time observable. A 'no-go' result called Pauli's theorem precludes this. The textbook interpretation of Pauli's theorem among physicists is as follows:

> [T]ime is just a parameter in quantum mechanics, and not an operator. In particular, time is not an observable [...] It is nonsensical to talk about the time operator in the same sense as we talk about the position operator (Sakurai, 1994: 66).

Pauli's theorem is typically taken to rule out the existence of time observables that are canonically conjugate to the Hamiltonian H. On this interpretation, any time translation invariant notion of temporal parts is doomed to fail. A self-adjoint time operator T canonically conjugate to H is needed to generate the shifts in the spectrum of H, which in turn is the generator of U_t (understood as a strongly continuous, one-parameter unitary group paramterised by energy). This doesn't mean abandoning U_t and the Schrödinger equation, it simply means that U_t does not involve such a one-parameter group parameterised by energy.

Pashby endorses a much weaker interpretation of Pauli's theorem (Pashby, 2014a: Ch.4). He believes that it merely restricts the form of any possible time operators. The real upshot of Pauli's theorem according to Pashby is the *spectral condition*. The spectral condition requires the allowed values of energy of a quantum system to have a lower bound. In other words, the spectral condition precludes the existence of Hamiltonian operators without a spectrum bounded from below. If we rejected the spectral condition, then we would be allowing for systems that can indefinitely transfer energy to their surroundings. This would be deeply unphysical; no systems that we know of do this. So, Pashby offers the following *reductio* of perdurantism:

P1. P_I is a PVM.

P2. $U^\dagger P_I U_t = P_{I-t}$.

P3. U_t is a unitary group produced by a self-adjoint operator H.

P4. H must have a lower bound. (Spectral Condition)

C1. For all I, $P_I = 0$.

C2. Hence, for all I and all $|\psi\rangle$, $P_I|\psi\rangle = 0$ (where 0 is the zero vector). (Pashby, 2013: 1145)

Pashby takes both P1, P2, and P3 to be necessary for the states $P_I|\psi_I\rangle$ to be temporal parts of $|\psi\rangle$, this follows from his ideas about what perdurantism is. However, quantum mechanics tells us that H must have a lower bound. This gives us the result $P_I|\psi\rangle = 0$, meaning that no quantum system $|\psi\rangle$ can have temporal parts.

Pashby suggests that we could relax P1 by using *position operator valued measures* (POVMs) rather than PVMs. Recall that a temporal PVM assigns a projection operator P_I to the interval I. A temporal POVM would be able to assign Hermitian positive semidefinite operators E_I greater than or equal to 0 to I. This gives us the quantum objects $E_I|\psi\rangle$. These behave similarly to temporal parts without being assigned to orthogonal subspaces. The objects $E_I|\psi\rangle$ give us a means of assigning properties to times. Temporal POVMs, unlike temporal PVMs, can obey time translation covariance. However, Pashby notes that we shouldn't view the objects $E_I|\psi\rangle$ as temporal parts. These assignments give us a covariant assignment of times to operators but they do not give us a temporal decomposition of the state space into distinct subspaces analogous to Pashby's notion of quantum spatial parthood. On this view, times are *not* associated uniquely with subspaces of $\mathbb{H}$. This is essentially a form of transdurantism, where properties are indexed to times in a perdurantist-like way without invoking temporal parts to do so.

4.4 TIME OBSERVABLES AND LOCALISATION

In 'How Do Things Persist? Location Relations in Physics and the Metaphysics of Persistence', Pashby admits that the perdurantist can avoid his previous argument by refusing to adopt his definition of quantum temporal parts. One could simply take the path of a quantum system to be the fusion of its many instantaneous spatial locations and then posit temporal parts for each of these instantaneous locations, for example.

Pashby concedes that this definition of temporal parts is not threatened by the spectral condition. However, he argues that the notion of quantum systems as *temporally extended* entities occupying a continuous spatiotemporal path is untenable. This is a problem for perdurantists who argue that objects must be temporally extended in this manner in order

to persist through time. This is an even more serious problem for perdurantists who reject instantaneous temporal parts in favour of extended temporal parts.[18]

Pashby argues that the spectral condition produces the following problem for locating quantum systems at temporally extended regions: First, we can take $P(\{t_k\})$ to be a projection operator denoting possession of the property P at every t within some interval t_k. Let the state $|\psi\rangle$ be in the range of $P(\{t_k\})$, such that $P(t)|\psi\rangle = |\psi\rangle$ for all times within the interval t_k. Then either,

1. $P(\{t_k\}) = P(\mathbb{R})$, or:
2. $\{t_k\}$ is a set with a zero Lebesgue measure (Pashby, 2014b; 2016).[19]

Hence, there is no projection $P(I)$ describing some property instantiated by an object at an open temporal interval and at no other time.[20]

Pashby notes that we can interpret this result in two ways: either any system confined to a spatial region for a temporal interval is confined to that region for all time or a nonzero probability that the system is localised outside of the region at any t entails that it is never actually localised inside the region (Pashby, 2016).[21] In other words, if we performed a localisation experiment then the particles we detect could never be measured outside of the lab at a different time. Admitting the very possibility that we could detect them outside of the lab in the future entails that they cannot be located inside the lab at more than a set of times with zero measure.[22]

If quantum systems are temporally extended objects with extended temporal parts, then they face the same kind of 'no-go' result presented in Pashby's earlier argument against quantum temporal parts.[23]

Pashby also claims that this raises a serious problem for the view that the quantum state provides a complete description of the properties of a persisting physical object (Pashby, 2014a; b). The spatial properties of these systems are very temporally sparse. We are left with a puzzling empirical result suggesting that persisting objects fail to be localised in a spatial region at most times or are stuck in one region at all times. Pashby

18 Jeremy Butterfield's (2006) 'anti-pointilliste' perdurantism is a prominent example.

19 It's important to note that this results from the same version of Pauli's Theorem that Pashby endorses. In both papers, Pashby uses a lemma from Hegerfeldt (1998) to present a proof of Pauli's Theorem (Pashby, 2013; 2016).

20 With this open interval being a subset of the real numbers $\mathbb{R}$.

21 If we were considering an infinite potential well (a particle trapped in a box), then the former interpretation would be correct. However, there are no known infinite potential wells in reality.

22 This result also applies to subregions. Localisation within a subregion of a region is just as restricted as localisation within the region itself.

23 But not all is lost for the perdurantist who endorses instantaneous temporal parts, since they can simply posit temporal parts for each instant that a system is localised upon measurement.

claims that this result implies that quantum states do not describe persisting objects. In what follows, I outline and respond to Pashby's preferred ontology of quantum systems and persistence.

4.5 PASHBY'S REITERATIONISM

Pashby contends that we can, and indeed should, understand localisation in terms of *events*. His event ontology forms the basis of his favoured theory of persistence, which he calls *reiterationism*.

Instead of treating $P_{\triangle}(t)$ as an experimental question about the position of some physical system asked at some t, Pashby interprets it as a proposition about the occurrence of an event in $\triangle$ at t. He notes that we do not need to radically change how we view localisation experiments in light of this:

> Picture a typical diffraction experiment which involves a source emitting a beam of particles, a diffraction grating through which the beam passes, and a luminescent screen. The source of quanta (electrons or photons, say) emits a single quantum particle at a time, at a frequency such that only a single particle is ever in the apparatus.
>
> Some time after a particle is emitted, a dot appears on the screen, and, repeating the experiment many times, the relative intensity of these discrete events comes to form a characteristic spatial interference pattern[…] the outcome of the experiment is an event […and] the time interval after which the dot appears will vary; finally, the screen is sensitive over the entire course of the experiment, and an individual experiment ends only when the particle is detected (Pashby, 2014b: 8).

But what exactly are 'events'? Pashby (2014b) outlines his view in reference to David Lewis's (1986) account of events as properties or classes of spatiotemporal regions.[24] The property is held by 'exactly one region of any world where the event occurs' (Lewis, 1986: 243). By 'exactly one', Lewis restricts the location of events to precisely one region and not any subregion or superregion. As such, a localisation event cannot occur both in $\triangle$ and in its superregion. We can distinguish here between an event occurring 'at' a region and an event occurring 'within' a region. Events occurring 'within' a region $\triangle$ also occur within every related subregion and superregion, whereas events occurring 'at' $\triangle$ do not.

The possible outcomes of a localisation experiment correspond to worlds in which a detection event occurs at t.[25] Probabilities are assigned once

24 Lewis uses the term 'property', but clarifies: 'By a property I mean simply a class. To have the property is to belong to the class' (Lewis, 1986: 244).

25 I make use of possible-worlds talk here, but Pashby (2014b) suggests that this is amenable both to ersatz views and possibly Alastair Wilson's *quantum modal realism* (Wilson, 2020). I'm not so sure about this, since Pashby's view seems difficult to combine with realist interpretations where the state only supplies part of the ontology (Wallace and Timpson, 2010).

an experiment begins and they concern if the event in question occurs at some t, along with the chances of detection at t. Anything that could have a probability of coming to pass is an event anyway, so it's not complicated to see how changing quantum states could supply probabilities for events to occur.

Pashby's event ontology puts pressure on him to take a controversial stance on the infamous measurement problem. By endorsing the forward implication of the eigenstate-eigenvalue link, Pashby was able to argue that quantum systems cannot be temporally extended. But in some interpretations of quantum mechanics, instantaneously localised states also require an infinite potential well (Wallace, 2014). Pashby points out that he can avoid this problem by endorsing both directions of the eigenstate-eigenvalue link with the Copenhagen interpretation (Pashby, 2016: 302-303). This would mean that quantum systems have some measurable quality F with value F when and only when the quantum state is in an eigenstate of F with eigenvalue F. However, Copenhagen interpretations are deeply unpopular among philosophers of physics. This would render Pashby's reiterationism deeply unattractive for philosophers who dislike the implications of adopting a Copenhagen interpretation and wavefunction antirealism. While Pashby's arguments are already inapplicable to Bohmianism, it's hard to deny that the 'standard' view of states giving a complete description of a persisting object is a far more natural fit for Everettian views than Pashby's event view.

Alternatively, Pashby could consider the 'flash' ontology version of the Ghirardi-Rimini-Weber (GRW) theory of spontaneous collapse. Ghirardi-Rimini-Weber theories suggest that the wave function does not always obey the Schrödinger equation, but rather have a small probability of undergoing spontaneous collapse at a fixed rate per particle per unit time (Dorato, 2015). Spontatneous collapse is represented by Gaussian functions which have a fixed width in physical space. In the flash ontology version (GRWf), an ontology of 'flashes' at spacetime points is postulated at the centre of the Gaussian function. These 'flashes' or 'jumps' of wave functions in the configuration space correspond to localised events in reality. The ontology of GRWf is ultimately composed of discrete events scattered in spacetime.

One worry is that Lewis's theory of events is too sparse and compatible with standard object-level ontologies, including Lewis's own, to feature as the basis of Pashby's reiterationism. Rather, Pashby's view seems to require events to be basic or perhaps identical to regions of spacetime. The latter view is endorsed by Bertrand Russell (1927), Donald Davidson (1980), and W.V.O. Quine (1985). This would completely avoid the difficulty that Pashby (2016) identifies with taking (spatiotemporally located) events to be ontologically prior to spacetime regions.

Pashby formulates reiterationism in reference to the views of Russell (1927) and Alfred North Whitehead (1925). One issue is that Russell and Whitehead do not share a theory of persistence. They have substantive metaphysical differences which leave Pashby's (2016) reiterationism an ambiguous view.

Whitehead's metaphysics was a forerunner of today's perdurantism. Like Pashby, Whitehead adopts an ontology of events or what he calls *actual occasions* (Whitehead, 1929: 18). Whitehead conceives of these events as parts of persisting processes, which he also calls *enduring objects*. (Whitehead, 1929: 34) Of course, these events are not identical to each other, so this is not a form of locative endurantism. However, I don't think that Pashby's view is identical to Whitehead's. This is because Whitehead's process ontology involves a number of extra metaphysical commitments, such as process theology. it's clear that Whitehead's theory of persistence is a form of perdurantism in all but name.[26]

In contrast, Russell rejects the idea that anything persists through time and change (Russell, 1927). Russell has no problem with the existence of groups of events unified by some scientifically-relevant relation. He does, however, have a problem with the idea that groups of events compose a persisting material object. Russell contends that this notion is 'empirically useless' (Russell, 1927: 248). Furthermore, he claims that since any series of events includes entities with different properties, so there cannot be a single object that shares all of these different properties. The latter claim is easily dealt with by perdurantist accounts where the bearers of contradictory properties are different temporal parts of the same four-dimensional entity. Russell's other claim that persistence is of no scientific value is more interesting, but still highly controversial. One might remark that persistence seems to play an important role in some areas of scientific inquiry. For example, the notion of detecting 'particle tracks' in a bubble chamber seems to involve the assumption that a sequence of bubbles is produced by the *same* particle over time (Goyal, 2019). Just as Whitehead's view was a forerunner of modern perdurantism, one might also say that Russell's 'no-persistence' view was a forerunner of a specific kind of modern perdurantism: a version of the stage theory without fusions.[27]

Pashby's (2016) view clearly cannot be the same as both Russell's and Whitehead's, since Russell and Whitehead have very different views. If it

26 We could try to construct a non-perdurantist, Whitehead-like process ontology. We could have a view where nothing fell in the range of the first-order quantifiers, but there was still variation in states of affairs over time. This would be a view where truth didn't supervene on being, since there are changes in events without changes in things. This wouldn't be a perdurantist view, but it would certainly be a confusing one.

27 An example of this might be Fabio Patrone's *pixelism*, which combines the stage theory with mereological nihilism (Patrone, 2020).

is a view like Whitehead's, then we're left with a form of perdurantism with extra baggage. If it is a view like Russell's, then we're left with a 'no-persistence' view that looks a lot like a nihilist version of the stage theory. Either way, we're back to working with things that could be principally called 'temporal parts'.

Pashby suggests that his view has an advantage in terms of parsimony (Pashby, 2014a). We need event-time observables, but we can do away with the notion of quantum systems as bizarre persisting objects. Pashby has a minimalist view similar to ontic structural realism where objects are eliminated from his ontology. The issue with this claim is that Pashby's view seems no different when we replace his talk of events with talk of instantaneous temporal parts. If events are nothing more than spacetime regions, then Pashby's events are no different from the 'objects' of supersubstantivalism, a view where objects are identical to their spacetime regions. Perdurantists have good reasons to take supersubstantivalism seriously, since they already believe that facts about the locations of objects supervene on the qualities of the locations themselves (Eagle, 2016). Pashby claims that we need event ontology because the odd, temporally sparse entities in his ontology are bizarre and don't correspond to common sense ideas about what objects are (Pashby, 2014b: 7). Maybe so, but I do not think there was ever any reason to believe that the objects of quantum mechanics would line up with our pretheoretical intuitions. They might not be the objects we were looking for, but if they are the entities that we have, then I see no reason to refrain from calling them 'objects'. There is no real advantage to positioning reiterationism as a minimalist alternative to object ontology, since we can endorse Pashby's reiterationism and get temporal parts along with quantum 'objects' for free.

4.6 QUANTUM PERDURANTISM REFORMULATED

But what if we choose not to define quantum temporal parts or temporal location with reference to a time observable? If we do this, then any project of defining quantum temporal parts parallel to Pashby's notion of quantum spatial parts is doomed from the start. But this does not mean that perdurantism is doomed. There might not be any time observables canonically conjugate to the Hamiltonian, but we still have time parameters in non-relativistic quantum mechanics. We could consider a time parameter parallel to external spatial coordinate parameters – the things which an event of a spatial localisation experiment is a localisation with respect to. If we define temporal parts in terms of an external time parameter, then we do not need to define them by gerrymandering a merely artefactual notion of quantum spatial parthood either. Unlike Pashby's

view, this view is not interpretation dependent. We do not need to adopt or reject a Copenhagen interpretation here.

On this approach, perduring quantum systems are not temporally extended with respect to a time observable but are simply extended with respect to time itself. Once we have this sort of picture, one might wonder why we ever expected quantum objects to be temporally extended persisting objects in the observable sense in the first place. Any view which respects the spectral condition is guaranteed to rule this out. With my view, we have no need to radically revise our metaphysics in the face of this result.

How do we make sense of localisation experiments? When we 'localise' a particular system, it gets localised to a bounded region. Outside of times where the system comes to be 'localised' as a result of instantaneous measurement, the system's temporal parts are imprecisely located at an unbounded region.[28] We are not relying on a time observable here, so we do not run into an objection from Pauli's Theorem. I agree with Pashby (2016) that we cannot assign a known exact location to a system not in an eigenstate of position. What we can do, however, is assign it a *weak location*. Josh Parsons gives the following informal gloss of weak location:

> I am weakly located in my office *iff* I am in my office in the weakest possible sense: *iff* my office is not completely free of me. I should count as weakly located in my office when I am sitting at my desk, when I am reaching an arm out of the window, or when I am reaching an arm in the window from the street outside (Parsons, 2007: 203).

We can follow Antony Eagle's suggestion of taking a quantum object not in an eigenstate of position to be 'weakly located at all and only those regions at which it has a non-zero chance of being found on measurement of position' (Eagle, 2019: 160). Their wave function is effectively spread out across space. These quantum objects, or rather their temporal parts, can still come to have an exact location on measurement. It makes sense that quantum objects are located somewhere even if they are not in an eigenstate of position. It would be very odd for these objects to be able to have a well-defined momentum if they weren't located anywhere.

It is technically the case that all quantum objects not in an eigenstate of position weakly coincide. Is this a problem? Hardly. Eagle (2019: 160) points out that we can still make claims about quantum objects to the effect that the objects have zero probability of being localised at the same region on measurement. This means that quantum systems can still be temporally extended objects that are exactly located at their path.

28 I feel a bit apologetic for retaining phrases like 'localised as a result of' to explain measurement, since I don't intend to take a stand on the measurement question like this sort of language might imply.

Pashby suggests that abandoning his definition of a quantum temporal part would mean abandoning a strict analogy between space and time (Pashby, 2013: 1144). Note Ted Sider's statement that 'the heart of four-dimensionalism is the claim that the part-whole relation behaves with respect to time analogously to how it behaves with respect to space' (Sider, 1997: 204). The commitment to this analogy is typically considered an advantage when defending a perdurantist ontology in a relativistic setting (Balashov, 2010). In addition, most perdurantists are B-theorists (Hawley, 2018: §6). They believe that change over time can be described in tenseless terms; that change over time is much like spatial variation. A banana ripening over time changes in much the same sort of way that a road changes its height as you traverse up a hill. If this analogy is abandoned and time turns out to be completely unlike space, then perdurantism might some of its dialectical force.

I don't think that abandoning Pashby's notion of quantum temporal parts actually has this consequence.[29] Defining quantum temporal parts with respect to a time parameter actually retains the analogy between space and time. Representing time by a parameter is not an issue, since space is represented by a parameter in quantum mechanics too. Pashby's quantum spatial and temporal parts do not draw an analogy between space and time, they actually draw an analogy between *position* and time. Hilgevoord (2005) points out that this is a fairly common conceptual confusion in quantum theory. He argues that one reason for this is that we tend to use spatial coordinates like x, y, and z to denote the eigenvalues of a particle's position observable. If the position operator's eigenvalues are identical to spatial regions, then it's no wonder that we might look for an operator with eigenvalues identical to times. However, the eigenvalues of position are *only* identical to spatial regions when considering a system with a single particle. Once we consider more complex systems in 3N configuration space, we should distinguish space and time coordinates from dynamical variables (Hilgevoord, 2002).

Thus, this does not generalise.

29 However, suppose that Pashby is right and this forces us to treat time and space differently. Still, this might not be a serious problem for perdurantism. Perdurantism does not require symmetry between space and time, despite Pashby's claims to the contrary. We don't need a strict analogy to hold between spatial parts and temporal parts. It is true that perdurantists often motivate their view by drawing an analogy between spatial parts and temporal parts. We're able to extend through space because we have spatial parts and we're able to extend through time because we have temporal parts. This has some pedagogical utility, since it's a good way to introduce the idea of temporal parts. Furthermore, perdurantists who absolutely refuse to permit the existence of time observables could simply adopt a disjunctive view: space and time are analogous in a relativistic setting but not in non-relativistic quantum mechanics.

On my view, non-relativistic quantum mechanics is understood as a theory of dynamic systems *in* a fixed spacetime.[30] Non-relativistic quantum mechanics is not a theory of spacetime. This is in direct contrast to theories like loop quantum gravity where there is no classical background spacetime. On Pashby's view, this understanding of non-relativistic quantum mechanics is rejected. Instead, event-time observables are included in an attempt to develop an event ontology of quantum mechanics.

4.7 CONCLUSION

I have shown that Pashby's arguments against perdurantism are ultimately unsuccessful. Perdurantists have a number of viable avenues to escape his *reductio* of the doctrine of temporal parts. Perhaps the most promising option is to concede that quantum systems are not temporally extended with respect to any time observable in quantum mechanics but are with respect to time as an external parameter. Pashby's treatment of quantum systems with respect to time as an observable puts pressure on him to adopt a discrete event ontology. Even then, Pashby's event ontology pushes him towards a theory of persistence that resembles two different historical antecedents of modern perdurantism and essentially a form of perdurantism in all but name. In conclusion, perdurantists do not face a 'no go' result from non-relativistic quantum mechanics.

30 This view is shared with Gordon Fleming (2014). It might also be shared by David Wallace and Christopher G. Timpson (2010).

Part III

CONCLUSION

5

Conclusion

In this conclusion, I provide a summary of the arguments detailed in the three essays. I also talk about some issues that I have not engaged with and point at directions for future research.

5.1 SUMMARY OF ARGUMENTS

In the first essay in the body of this thesis, I responded to the objection that the worm theory cannot account for our intuitions about ordinary counting sentences. Many perdurantists have responded to this objection by rejecting the worm theory in favour of the stage theory. However, I argued that the worm theory is still salvageable. In fact, I think that my version of the worm theory does a better job than its stage-theoretic alternatives.

Furthermore, my version of the worm theory also presents a unified account of object- and event-related counting sentences. Event-related counting sentences turn out to be a species of object-related counting sentences. My account of event-related counting sentences is similar to Barker's, but my view does not invoke a disjunctive interpretation of quantifiers or multiple kinds of 'identity' relations.

The main consequence of my argument in Counting for Worm Theorists is that I eliminate the main motivation for adopting the stage theory. Many philosophers have adopted the stage theory in response to the counting problems faced by the worm theory. But it turns out that the worm theory, once supplemented with situation semantics, actually provides the best perdurantist account of ordinary counting sentences. So one might well suggest that we should never have abandoned the worm theory in the first place.

The second essay fleshed out a distinction between parts-first, no-priority, and wholes-first perdurantism. I explored ways that one might motivate these different views and different ways they could be formulated. We have good reasons to treat parts-first perdurantism as the orthodox perdurantist view. It helps motivate mereological universalism, which is central to the Lewisian perdurantist worldview. In contrast, wholes-first perdurantism does not fit well with mereological universalism. Such a view might be more attractive for those who endorse restricted composition.

I suggested that these views point towards a conflict between mereological perdurantism and so-called locative perdurantism. Those who take the claim that objects are four-dimensional entities more seriously than the claim that they persist in virtue of their temporal parts might find themselves in favour of wholes-first perdurantism, whereas mereological perdurantists should adopt a parts-first view.

In contrast to Buonomo and Heller, I argued that different views regarding priority should not be seen as reflecting different views about phenomenology. While they have motivated the distinction between parts-first, no-priority, and wholes-first views in this way, it turns out that the distinction does not play an illuminative role when discussing phenomenology.

Instead, I argued that different ways of accounting for persistence in Minkowski spacetime reflect different views about mereological priority. The relativity of simultaneity presents an interesting scenario, since we have ways of developing both wholes-first and parts-first accounts. I suggested that we could modify Balashov's relativistic argument for pedurantism and against endurantism to be an argument for wholes-first perdurantism. Although the argument fails, we are left with the choice between an account where many point-sized spatiotemporal parts are prior to their four-dimensional fusions and an account where four-dimensional objects are prior to their parts.

Perdurantism and Priority is mostly a surveyal paper. My contributions to the literature are more minor than they are in Counting for Worm Theorists. I explored the distinction between parts-first, no-priority, and wholes-first perdurantism in detail while arguing against the claim that phenomenological arguments favour any particular view here.

In How (Quantum) Things Persist, I showed how some recent arguments from non-relativistic quantum mechanics against perdurantism fail. I pointed out that Pashby's first argument against perdurantism runs into some problems. For example, notion of quantum spatial parts and quantum temporal parts is not an appealing one. Some of his claims about the significance of the worm theory/stage theory distinction for quantum dynamics are also suspect. Both of his arguments rely on the assumption that we must define quantum temporal parts and temporal location with reference to a time observable.

This assumption motivates Pashby's adoption of an event ontology, which he calls reiterationism. I argued that Pashby's reiterationism pressures him to take a controversial stand on the measurement problem and requires a more robust notion of 'event' than he provides. I note that Pashby's view, if we are to make much sense of it at all, is simply a bizarre form of perdurantism.

I rejected Pashby's assumption that we should define quantum temporal parts with reference to a time observable. Instead, I pointed out how we could define quantum temporal parts in terms of an external time parameter. This makes more sense than expecting quantum objects to be temporally extended in the observable sense. I also argued that does not force us to abandon the popular perdurantist analogy between space and time, since space is also a parameter in quantum mechanics. The upshot of this essay is that perdurantists do not face a 'no go' result from non-relativistic quantum mechanics.

5.2 DIRECTIONS FOR FUTURE RESEARCH

It would be silly of me to claim that I have addressed all issues in the metaphysics of persistence here. Several worthwhile questions remain to be answered, either in greater detail or at all. For instance, in my first paper, I assumed that counting is by identity. There are, however, those who disagree with this assumption. David Liebesman (2015) argues that we are unable to account for sentences that express counts given by non-natural numbers, such as fractions, if we count by identity. Oliver R. Marshall (2017) responds by treating sentences indicating fractions as measurement sentences instead of counting sentences. He thinks that we ought to interpret utterances of 'there are two and a half oranges on the table' as measuring quantities of orange-stuff. Eric Snyder and Jefferson Barlew (2019) develop a view where 'there are two and a half oranges on the table' is ambiguous between counting interpretations, where we count two oranges and one half orange, and measuring interpretations. It might be an interesting project to try to defend the claim that these are counting sentences and that we don't need to adopt an measuring interpretation of them. There are objections to this view, namely that it struggles to account with cases like following an utterance of 'there are two and a half bagles are on the kitchen table' up with 'twice as many onions as that are on the dining room table' (Liebesman, 2015: 27). 'That' seems to designate a number value of 2.5. Can we interpret 'that' differently? I'm not entirely sure and so I think that the question warrants further investigation.

Many of the ideas in Perdurantism and Priority could be developed further independently. Whether perdurantists committed to any additional ontological theses is one example. Notions of priority and grounding were briefly introduced but have a vast literature of their own. There is considerable debate about what exactly grounding is and what entities it can apply to. I also think that I could explore the idea of no-priority mereol-

ogy in greater detail. Similarly, I think some of the versions of wholes-first perdurantism that I briefly outlined could be developed further.

My third paper, How (Quantum) Things Persist, discussed non-relativistic quantum mechanics but not theories which attempt to combine the empirical successes of quantum mechanics and general relativity. It would be interesting to see how we might think about persistence in the context of quantum field theory or theories of quantum gravity like string theory and loop quantum gravity. In a relativistic setting, we do not have a fixed classical spacetime to fall back on. Point-sized particles are replaced with one-dimensional strings in string theory, which may present unique challenges for both perdurantists and endurantists. In addition, both string theory and loop quantum gravity present problems for the idea that spacetime is fundamental. Most formulations of loop quantum gravity are manifestly background-independent; there is no fixed spacetime background as found in classic mechanics and special relativity. While I do not think that non-relativistic quantum mechanics decisively settles the issue of persistence, it is possible that some other theory might. More generally, I think it would be a useful project to see how we might make sense of persistence in these theories.

I did not explore the issue of location in great detail. It comes up at various junctures, but I did not provide a systematic account of locative relations. There remains considerable debate over location in metaphysics. For example, philosophers disagree over which locative relations, if any, should be taken as primitive (Gilmore, 2008). The central disagreement between so-called locative endurantists and perdurantists concerns whether an object's exact location is unique and whether objects must be temporally extended. If multiple location is impossible, then multi-location endurantism must be ruled out. Similarly, we must rule out locative perdurantism if temporal extension turns out to be impossible. It might also turn out that our existing locative relations fail in the face of fundamental physical theories. These are all issues worth exploring in further detail.

There are, of course, many other issues that I have not explored in this thesis. I briefly discussed some of these in the Introduction. While many of these issues have been discussed by other philosophers in great detail, many questions remain unsettled. I assumed a B-theory of time throughout this thesis, but what exactly is our best theory of the metaphysics of time? If it turns out to be a B-theoretic view, then what exactly should it look like? We could try to salvage the apparent 'dynamic' nature of time by appealing to our temporal phenomenology or we could advocate for eliminating time from our ontology altogether.

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