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The ROM Theory of the Specious Present

A dissertation submitted in partial satisfaction of the
Requirements for the degree Doctor of Philosophy

in

Philosophy and Cognitive Science

by

Matthew Stuart Piper

Committee in charge:

Professor Rick Grush, Chair
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Professor Gary Cottrell
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2020

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The dissertation of Matthew Stuart Piper is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

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Chair

University of California San Diego

2020

DEDICATION

I dedicate this academic work to all those who have supported, encouraged and inspired me, on the one hand, and to all those who will absorb its contents, on the other.

I would like to give special thanks to my grandfather Jack and my parents for being so supererogatory in their efforts on my behalf. I dedicate this as well to my siblings and my girlfriends through the PhD process, all of whom have always been my closest friends. I am indebted to all of them in many, many ways, and I love them all.

Lastly, I dedicate this work to my favorite creators of all time – in the arts and the sciences – too numerous to mention…

EPIGRAPH

Only the artist or free scholar
Carries his happiness with him.

- Ludwig van Beethoven

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I would like to thank Professor Rick Grush for his insight, honesty and willingness to challenge me. His initial skepticism of my project was a key catalyst, and his later admission of the success of my neutralization of his stock argument was truly a great honor. I'll never forget the generosity and nobility of that. That is academia at its best.

I would also like to thank the rest of my committee members, especially Professors Matt Fulkerson and Brad Voytek. Matt is an outstanding philosophy teacher in all senses, and an inspiration. Brad very graciously let me join his lab meetings, from which I garnered a good deal, and was my sole mentor in discussing the nature of brain oscillations.

Finally, parts of chapter 4 and 5 were published in 2019 by the journal *Consciousness and Cognition*. The dissertation author was the primary investigator and author of this paper.

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ABSTRACT OF THE DISSERTATION

The ROM Theory of the Specious Present

by

Matthew Stuart Piper

Doctor of Philosophy in Philosophy and Cognitive Science

University of California San Diego 2020

Professor Rick Grush, Chair

This dissertation situates an original model of reentrant oscillatory multiplexing (ROM) within the philosophy of time consciousness to argue for an extensionalist theory of the specious present. I develop a detailed differential latency model of apparent motion to show how the ordinality of experiential content is isomorphic to the ordinality of relevant brain processes. I argue that the theory presented has resources to account for

other key features of the specious present, including the representational discreteness between successive conscious moments as well as the phenomenological continuity between them. I go on to illustrate the consonance of ROM theory with state dependent networks, population clocks and predictive processing models. This work not only shows the plausibility of an extensionalist philosophical theory, it also illustrates the utility of differential latency views in squaring temporal illusions with empirically supported neurodynamics.

<u>Chapter 1: Dissertation Preview and Working Assumptions</u>

1.1. Dissertation Overview

This dissertation is about the nature of temporal consciousness, and specifically about our immanent perception of temporal passage. Consider the oft-cited phenomenology of seeing a shooting star: even though motion and change are experienced as the meteor briefly falls, the entire event is experienced in one perceptual gulp, as a single conscious moment. Roughly speaking, the sense of immanence I'll be discussing corresponds to experiences around a second or less – a time frame that William James' (1890) called "the specious present": "the short duration of which we are immanently and immediately sensible."[1] The concept of the specious present involves two ideas. First, that our immediate experience of time and temporal experience is an experience of the *present* moment. In physics and other sciences, the "present" is often characterized as an instant. However, and secondly, since all experiences appear to have temporal breadth, James dubbed it the "specious" present. Regardless of the historical roots, the topic of this dissertation is the neurobiology underpinning the specious present.

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[1] This characterization does not imply specious presents have a set, invariable duration, a claim I reject as implausible on both experimental and neurodynamical grounds (see chs. 5 and 6).
[2] Alternatives to the computational theory of mind include, for example, enactive, embodied and dynamic theories of mind among others (I return to this in ch. 5).
[3] There is a large literature on the nature of realization. For the most part, space requires bracketing these issues. When I refer to the neurodynamical realizers of temporal experience, I principally have in mind what Matthew Haug (2010) calls the "constitutive mechanism" of temporal experience – i.e., the set of physical properties that is responsible through their causal interactions for bringing about the relevant mental properties. Following the lead of the main discussants in the temporal experience debate, I will remain neutral on many metaphysical issues about the mind-body relation, aside from assuming a basic naturalism.
[4] In addition to providing a constitutive mechanism for explaining how temporal experience is realized in neurodynamics, reentrant oscillatory multiplexing is also intended as an "integrative mechanism," to use

James' terms "immanently" and "immediately" are critical here. Obviously we can be aware, in some sense, of significant durations – as during the recollection of a song, an afternoon, a trip or even longer. But these types of awareness of extended durations are essentially conceptual and memory-dependent types of awareness: we're not in perceptual contact with the whole of those experiences all at once. The target of my inquiry, by contrast, is the short duration that we subjectively perceive *all at once*. By convention, I will call this duration the specious present. My goal is not to provide a universal theory of time consciousness, nor to account for all temporal phenomena (cf. Viera, 2016; 2019); rather, my claims are restricted to the specious present.

What motivates an inquiry into the temporal perception of the specious present? Temporal perception of the specious present is an especially interesting inquiry for a number of reasons. First, we have no sensory receptors for perceiving time, yet all conscious experience seems to involve the experience of temporal extension (James, 1890; Stern, 1897; Pelzcar, 2010; Dainton, 2014). Normally, we require specialized receptors to experience stimuli of various kinds: functioning retinas and visual cortex for visual perception, functioning cochlea and auditory cortex for auditory perception, and so forth for other sensory modalities. Yet there has been no discovery of a trauma or ablation that has removed the specious present without also ablating consciousness *simpliciter*. This, I suggest, is more than fascinating: it is absolutely essential to understanding consciousness. It suggests that the nature of consciousness and the nature of the specious present are intimately intertwined, if not identical. And this is not a new suggestion. Similar thoughts are found throughout philosophy, notably in Kant, James, Stern and Husserl, e.g. Although not a new idea in philosophy, it will get a new treatment here, for I aim to provide a neurobiological theory for this observation. If correct, a classic idea will have novel and very current empirical grounding.

The foregoing suggests a very closely related second point: that temporal extension and temporal representation is arguably an intrinsic feature of all experience (ibid.). In the literature about time consciousness, the discussion of temporal representation is sometimes thought of as one type of representational content among others that can be discussed independently of basic consciousness. And prima facie, this makes conceptual sense: why associate any one type of representational content with consciousness? But it's a live possibility – and one I advocate – that there is no consciousness without temporal representation, even if consciousness can obtain in the absence of every other type of representational content. We can lose vision, hearing, touch, taste, smell, pain, spatial orientation, etc. while being conscious, but if we're conscious we experience a sense of internal temporal passage. So, again, maybe understanding the temporal representational content of the specious present is *a key* to understanding consciousness simpliciter.

Both of the foregoing ideas suggest a related third point, which is that whatever its exact nature, the role of time is foundational in the organization of the cognitive economy (Cohen, 2011; Maniadakis and Trahanias, 2014; Paton and Buonomano, 2018). Consciousness and the cognitive economy are closely related, but distinct concepts. While consciousness cannot be discussed without implying the concepts of "experience" and "phenomenology," cognition does not imply those ideas. Cognition is a term of art, but many if not most philosophers espouse some kind of computational theory of cognition, in which cognition concerns the manipulation of mental representations, conscious and unconscious (Rescorla, 2015).[2] As Freud made famous, a lot of our mental activity – our cognition – takes place below the surface of consciousness: the realm of unconscious or pre-conscious influences. And influential neuroscientists interested in consciousness usually make this distinction as well (e.g., Dehaene et al., 2001; 2006). So the idea that cognition is inherently temporal takes the importance a step further. But the rationale is very straightforward: the manipulation, or transformation, of mental representations – i.e., cognition – is inherently temporally structured. The order in which transformations occur is just as important as what transformations are involved (which themselves may be temporal in nature (Buonomano, 2014; Paton and Buonomano, 2018)). The upshot, then, is that cognition is inherently temporal. If so, the understanding of the specious present will also shed light on the cognition occurring during immanent temporal consciousness.

An overarching motivation for the foregoing ideas has been previously described in the following way: time is key to understanding the brain, the mind and consciousness because temporal representational contents, compared to other perceptual contents, are uniquely positioned to apply isomorphically to both experience and the brain, since experiences are essentially characterized by their temporal features (Dainton, 2014; Phillips, 2014). Phillips (2014) puts it like this:

> …time is special. Temporal properties are the only properties manifestly shared by both the objects of experience and experience itself. Experience, at least in its subjective aspect, is not colored or shaped; it does, however, manifestly have a temporal structure (p. 139).

[2] Alternatives to the computational theory of mind include, for example, enactive, embodied and dynamic theories of mind among others (I return to this in ch. 5).

These ideas illustrate some of the motivations behind my project. My interest in the specious present concerns its nature, and most especially its relation to the neurodynamical processes that generate it. I will defend an "extensionalist" view of the nature of immanent temporal consciousness by arguing that a resemblance relationship exists between temporal representational content of experiences and the neurodynamical processes that generate them. More specifically, I will argue that the timing of the brain processes that realize experiences of the specious present explain the temporal representational properties of those experiences. My argument turns therefore on the neurodynamical realization of the specious present.[3]

It is important to highlight an implicit distinction here. We need to distinguish 3 factors at play in describing our experiences and their generation. First, there is brain timing: the timing of the neural processes – the neurodynamics – that generate conscious experiences. Second, there is temporal representational content: this is the proprietary temporal nature of conscious experience. In discussing the specious present, the temporal representational content is how the present is temporally experienced. Third, there is temporal content: the temporal reference of the content experienced; where along the world timeline the content refers. Rick Grush (per. comm., 2020) gives a good example of the distinction:

> …when I remember my 5th birthday, the content is way in the past [i.e., temporal content], my experiencing the memory is in the present [i.e,. temporal

[3] There is a large literature on the nature of realization. For the most part, space requires bracketing these issues. When I refer to the neurodynamical realizers of temporal experience, I principally have in mind what Matthew Haug (2010) calls the "constitutive mechanism" of temporal experience – i.e., the set of physical properties that is responsible through their causal interactions for bringing about the relevant mental properties. Following the lead of the main discussants in the temporal experience debate, I will remain neutral on many metaphysical issues about the mind-body relation, aside from assuming a basic naturalism.

> representational content], and then there are the neural events implementing my memory experience [i.e, brain time].

My focus is on the relationship between the second [temporal representational content] and third [brain time] concepts. My interest in explaining the nature of the neurodynamical realizers situates the discussion squarely in an ongoing discourse about the relationship between the representational vehicles and representational contents of the specious present. Put in these terms, I will argue that the temporal properties of the representational vehicles of the specious present explain, through resemblance, the temporal representational content of the specious present. In providing an explanation for why the temporal representational content of the specious present has the character it does, my project is thereby also a defense of a resemblance theory of specious present content determination, and thus makes contact with theories of representational content determination more broadly.

All the conclusions I will defend will be packaged as aspects of a view I call ROM theory, where ROM stands for "reentrant oscillatory multiplexing." In broad strokes, ROM theory has two parts: (1) a theory of the nature of temporal representational vehicles and (2) a theory of how those vehicles determine temporal representational content. In this way ROM theory is a theory of the vehicle-content relation of the specious present, or a theory of temporal representational content determination of the specious present. As mentioned, I am only concerned with an explanation of the specious present range of temporal experience, though I suspect ROM theory's explanatory merits are wider, a speculation I will later explain.

(1) ROM theory holds that temporal representational vehicles have three levels of structure, corresponding to (i) oscillations that are (ii) multiplexed in (iii) reentrant circuits.[4] Roughly speaking, oscillations are rhythmic fluctuations in neural excitability and activity; multiplexing is the integration of multiple signals within a unified signal; and reentrant circuits combine feedforward and feedback signals into a circuit within which the sources of feedforward and feedback signals reciprocally affect local signaling and neural connectivity.

(2) ROM theory holds a version of the simplest type of theory of temporal representational content determination: resemblance (cf. Shea, 2014). Roughly, such positions hold that the nature of temporal representational content is inherited from, and hence resembles, the temporal profile of temporal vehicles. Resemblance can take various forms. For example, "topological mirroring" (Lee, 2014b) is the claim that the order presented in temporal experience is determined by the order of vehicular dynamics, and what we might call "continuity mirroring" holds that the continuity of temporal experience resembles, because is generated by, continuous vehicular dynamics. ROM is a defense of both of the just mentioned mirroring constraints, as well as others. I turn to an enumeration of the kinds of resemblance defended herein via an initial characterization of the nature of temporal content to be discussed.

[4] In addition to providing a constitutive mechanism for explaining how temporal experience is realized in neurodynamics, reentrant oscillatory multiplexing is also intended as an "integrative mechanism," to use Haug's (2010) terminology. This is the case because ROM circuitry is a plausible condition for representation *simpliciter* (see below).

1.2. Characterization of the Temporal Content of the Specious Present

1.2.1. Basic Types of Specious Present Content

There are three predominant types of explicit temporal experience that are experimentally studied: simultaneity, ordinality (order of succession), and interval duration. And these give rise to four interesting types of temporal content arising in experiment. (i) At very fast presentation speeds – i.e., very small interstimulus intervals (ISIs) – there is the experience of stimulus simultaneity. *Simultaneous* contents are those that cannot be distinguished on temporal grounds. (ii) At slightly longer ISIs, there is an experience of non-simultaneity, but, oddly enough, temporal order cannot be determined; the subject is aware of temporal asymmetry between A and B, but is at chance to decide which was first – call this *temporal order blindsight (TOB)*. (iii) At still larger ISIs, clear succession and *explicitly ordinal* judgments are possible. (iv) And at those and especially longer ISIs, a metric sense of interval or *duration* enters the phenomenological fold. In addition, there are desiderata that aren't so much studied as are simply broadly endorsed through introspection: these include (v) temporal *extension* and (vi) a sense of *continuity or flow*. Upon naïve reflection, temporal experience seems non-punctate (extended) as well as unbroken or non-gappy (continuous or flowing). These are the six most obvious desiderata relevant to the discussion. Note that it isn't clear that all of these phenomena should submit to the same explanations; a point reinforced by evidence that different temporal phenomena are plausibly generated by distinct mechanisms, distinct circuits, or some combination (Nobre and Muller, 2014; Paton and Buonomano, 2018). In this dissertation, I will outline how ROM theory makes restricted claims about the nature of temporal experience, focusing on all of the above-mentioned features.

1.2.2. Philosophical Delimitation of Specious Present Explananda

There are a number of important distinctions about consciousness that philosophers have articulated that are relevant to a discussion of temporal consciousness. One is the distinction between phenomenal properties and representational properties. These are terms of art, but the basic distinction involves the way things seem, or are presented to, a subject vs. the way things are represented by a subject. The latter is typically referred to as representational content and many have argued it can be naturalized – i.e., explained without recourse to phenomenal (1^{st} person) terms. Consequently, an important but vexed question concerns the exact relationship between phenomenal and representational properties. This bears on the present discussion because it must be determined how many explananda there are. This dissertation will focus on temporal representational content, but should it also include an analysis of temporal phenomenal character?

Generally speaking, the literature on temporal consciousness has historically omitted any such discussion. And there are two good reasons. First, since the exact relation between phenomenal and representational properties is itself unknown and a source of intense debate, attempting to resolve such an issue from scratch is both implausible and would impede a sufficient discussion of the relevant literature. The second reason is the influence of representational theories of consciousness. There are many kinds of such theories but they share a commitment to the idea that representational content is the ground for all other properties of consciousness. Following the literature, then, I will bracket a discussion of the relation between phenomenal and representational properties, but I owe the reader an account at least of what I will be assuming.

This manuscript is written under the assumption of “weak representationalism,” which roughly holds that while phenomenal and representational properties are distinct, the former supervene on the latter; that is, there can be no change in phenomenal properties without a change in representational properties. This popular position recognizes the epistemic gap between first-person phenomenal properties and representational properties that, as mentioned, are often hoped to be fully characterizable in third-person terms. At the same time, it justifies focusing exclusively on temporal representational content, since it lays the foundation for an account that can potentially illuminate the basis of temporal phenomenal character as well.

Thus, this dissertation assumes that temporal consciousness has both phenomenological character and representational content but that the former supervenes on the latter. This assumption that the phenomenological character of temporal consciousness will be elucidated by an analysis parallel to the one provided in terms of representational content provides a reason for couching the discussion solely in terms of temporal representational content.

Given that the target is the temporal representational content of the specious present, it seems critical to get more precise about the scope of the specious present.

1.2.3. Operational Delimitation of the Specious Present

Two general strategies for delimiting the explanatory scope of temporal experience are quantitative and qualitative. A quantitative approach involves distinguishing temporal representational contents by temporal ranges derived from experiment or theory. Various theorists, for example, have posited three nested ranges of temporal experience, corresponding to (i) very brief functional moments, (ii) a short interval of the experienced "now," and (iii) a longer interval of the experienced present (Poppel, 1997; Wittman, 2011; Prinz, 2012). However, there is no agreed upon quantitative approach.

Since there isn't an established view of how many temporal scales exist or how to quantify them, I am going to focus on the much discussed concept of the specious present, which can be roughly characterized as *the maximal interval during which we can directly and holistically perceive change and succession* (cf. James, 1890; Stern, 1897; Tye, 2003; Hoerl, 2013). Thus, this dissertation concerns itself with the specious present, as perceptually defined. Although the specious present is the most discussed temporal scale concept, its temporal boundaries are a matter of longstanding dispute (see Rashbrook-Cooper (2016) for a justification of why no resolution should be expected).[5] This reinforces taking a qualitative approach at this stage.

The specious present doctrine contrasts with a "cinematic" view that temporal representational content is presented in instants, not intervals. Advocates of the specious

[5] Estimates of the subjective duration of the specious present range from 30+ ms (Tye), 200-300 ms (Grush), ~300 ms (Strawson*), ~500 ms (Dainton), ~750 ms (Benussi*), 1-1.5 seconds (Lockwood*), 2-3 seconds (Wittmann, 2011/2016; Poppel and Bao, 2014) to 100-5000 ms (Fraisse*) * Cited in Dainton (2010).

present doctrine believe that temporal experience directly represents temporal extension; advocates of contrasting views believe that temporal experience only represents instantaneous perceptual moments. The biggest criticism of non-specious present views is that it is self-evident that we directly experience temporally extended phenomena, like motion and melody. Since the preponderance of work on temporal experience employs the specious present concept, I'll assume it is a viable framework, reserving arguments against the rival cinematic view until chapters 3 and 6.[6]

The central conceptual issue about specious presents is how temporal contents within the specious present can appear both simultaneous (in the sense of being part of a complex phenomenologically unified *present*) and temporally differentiated. That is, how can the specious present manifest both temporal immanence and temporal extension (Hoerl, 2013)? The most popular philosophical theories of temporal consciousness are essentially answers to this question and will be unpacked in the next chapter and examined in the third.

There is a serious obstacle to be flagged. Since there isn't an agreed upon length to the interval represented by the specious present, different theorists focus upon distinct temporal contents. As will be discussed below, this is reflected in different explanatory targets of the philosophical theories. For my purposes, I will take the specious present to be constituted by the interval that includes any temporal content that can be immediately, immanently or directly experienced.[7] This is in contrast to a theory attempting to also

[6] One idea worth exploring is whether it makes sense to consider the possibility of multiple ways of characterizing the specious present. There might be multiple ways to characterize the specious present, with each way corresponding to distinct kinds of temporal experiences apprehended within different mental states. For example, would it be useful to distinguish between a perceptual specious present and a specious present appropriate to working-memory-dependent reflective self-consciousness?
[7] I use the terms immediate, immanent and direct as synonyms.

explain various kinds of temporal inferences, temporal priming or non-phenomenological temporal contextualization.

1.2.4. Philosophical Characterization of the Representational Content of the Specious Present

To help further narrow down the explanatory target, I turn to an adumbration of the representational nature of the specious present, as I will characterize it. What is the nature of the representational content of the specious present? These are not trivial questions and can be contested. In the temporal perception literature, these kinds of questions are normally bracketed (though see Hoerl, 2017) in favor of getting on with a debate grounded in an introspective phenomenon intimately familiar to all discussants. Following suit, I will not make detailed arguments for the following claims. Rather, these are offered to give the reader an idea of the nature of the representational content I take the specious present to generate, and the kind of content I hope to provide an explanation for.

I take the proprietary representational content of immanent temporal consciousness – the perceptually-defined specious present – to have the following characteristics.

One, the representational content of the specious present is non-conceptual in the philosophical sense that immanent temporal phenomenology doesn't rely on conceptual representation or capacities for such – intuitively and observationally, the specious present is phenomenologically similar for complex mammals, and there is no reason to think many otherwise conscious beings (such as rats, cats or deer) have an experience of immediate temporal passage imbued with abstract conceptual content.

Two, while immanent temporal content often parallels rates of change in the external environment in order to guide action, the experience of the specious present in dreams and the phenomenology characterizing various temporal distortions shows that immanent temporal content fundamentally arises from encapsulated internal processes and is thus fundamentally narrow content – i.,e., defined by psychological role (cf. Arstila, 2016b/2017; Hohwy, 2016; Montemayor, 2017).

Three, the specious present is best characterized by earlier-than/later-than/simultaneity relations (what Grush, 2016, calls B-ish contents), as opposed to (A-ish) tensed past/future/present concepts (see Hoerl, 2009; Grush, 2016). As Hoerl (2009) and others have sagely analyzed, importing past and future concepts into a discussion of a perceptually-defined specious present creates a number of confusions. For example, how is it possible to perceive the past? The idea is that involving Aish-contents into discussions of the specious present seems to have created a number of unnecessary paradoxes, like the preceding. Another unsolved question is "what is the nature of retention in retentionalist theories?" Since retention and protention are fundamental concepts to the retentionalist picture, and its A-ish concept of temporal representational content, this is a serious problem. However, if we reject the A-ish conceptualization of the specious present, these paradoxes evaporate. Although Hoerl (2009) advocates for the view that the specious present is tenseless or untensed, also avoiding the A-ish paradoxes, I prefer to say that it is singly tensed: the specious present necessarily presents itself as a flowing "now" (cf. Hohwy et al., 2016). But because the window of this moving "now" isn't punctate, it is thick enough to contain a sense of succession, which implies earlier-than/later-than relationships. And because the entire temporal representational content of a specious present is unified in one perceptual gulp, there isn't a substantive or valid sense of "past" or "future" in play.

Now that some philosophical preliminaries are out of the way, and the reader has a clearer idea of my initial assumptions, I turn to a characterization of the main debate at issue.

1.3. Overview of the Vehicle-Content Debate about the Specious Present

There are two *main* views in the debate (Grush, 2007; Hoerl, 2009; Dainton, 2010; Lee, 2014), and they both agree that the representational content of our immediate experience presents a temporal interval, but they disagree over the nature of the relationship between that content and the processes that generate it.[8] There are various ways to characterize and label these rival views[9], but the basic dichotomy in which I'm interested concerns whether the temporal properties experienced during the specious

[8] As mentioned, the rejection of the specious present doctrine forms a class of "cinematic" theories, which are unified in taking experiential content to be punctate or instantaneous/static. On such views, the direct experience of motion and change must be accounted for via either (a) the comparison of static perceptual contents through memory faculties (Le Poidevin, 2007) or (b) special perceptual mechanisms (Arstila, 2017). Below, I discuss reasons to eschew cinematic theories generally, but the main objection can be quickly conveyed. Since we have experiences of motion and change, there is a heavy burden on the cinematic theorist to explain such experiences in light of her axiom that experiential content only comes in static "snapshots". The core problem is how to account for motion content in fundamentally static terms. The core suspicion of non-cinematic theorists is that the cinematic theorist can only account for motion content by contradicting her own view at some point. I will defend this claim below.

[9] E.g, Grush (2007) and Dainton (2010) debate extensionalist v. retentionalist positions; Hoerl (2009) argues for a molecularist, and against an atomist view, of the specious present; Lee (2014) defends an atomist view against objections from extensionalists, while Rashbrook-Cooper (2017) argues for extensionalism and against atomism. Arstila and Lloyd (2014), Montemayor (2017) and Viera (2019) present, in distinct ways, hybrid models of temporal experience, carving out space for both extensionalist and atomist characterizations of different aspects of temporal experience.

present are, or are not, explained by resemblance with the temporal properties of experiences. Extensionalists, on the one hand, explain the features of experienced time via resemblance to the temporal features of conscious experiences (Stern, 1897; Hoerl, 2009; Dainton, 2010; Philips, 2014). On this view, the order and temporal extension of conscious contents *is explained by* the order and temporal extension of experiential processes. Atomists, on the other hand, do not think the timing of experiential processes explains the temporal representational content presented in experiences (Dennett and Kinsbourne, 1992; Grush, 2007; Lee, 2014). Collectively, they hold that experiential processes are much briefer than the temporal interval experienced and can also invert ordinality, thus violating various kinds of resemblance. Hence, the central question in this literature is whether or not the immediate experience of time is, or is not, explained by the temporal nature of experience itself.

Although philosophers have tended to describe the debate in brain-neutral terms, I think the most perspicuous way to unpack the issue is around the distinction between brain time (i.e., the timing of neural processes) and experienced time (i.e,. time as consciously experienced).[10] Extensionalists hold there is an explanatory resemblance between the two (brain time -> experienced time); atomists deny that any such resemblance, even if it existed, would be explanatory.[11]

[10] Here, I am assuming that temporal representational content is realized by representational vehicles, and that such vehicles are brain/neural processes. Extensionalists hold that the representational content of a specious present is explained via resemblance to the temporal properties of representational vehicles. Atomists deny this.

[11] Putting the debate this way helps reveal how developments in the neurosciences dovetail with sometimes insular philosophical discussions on temporal consciousness. Specifically, neuroscientific differential latency views – which hold that apparent mismatches in brain time and experienced time can be harmonized by taking account of the fact that processing latencies depend on stimulus features, task conditions, and attentive focus, etc. (Breitmeyer and Ganz, 1976; Purushothanam et al., 1998; Whitney and Murakami, 1998; Patel et al., 2000; Bedell et al., 2003; Ogmen et al., 2004; Baldo and Caticha, 2005; Bachmann, 2013; Wutz and Melcher, 2014) – can be appreciated as natural allies of the extensionalist

Atomist-type views have attracted many adherents (Husserl, 2014; Dennett and Kinsbourne, 1992; Grush, 2007; Lee, 2014; Molder, 2014; Gallagher, 2017). There are three main reasons. First, in general, representational contents don't resemble and aren't resembled by the properties of representing processes. Consciously representing something as red or heavy doesn't involve, nor would be explained by, brain processes becoming red or heavy, for example. Prima facie, the same could be assumed for temporal representation: i.e., that temporal representational content isn't explained through resemblance with neurodynamical processing time. Second, many find it intuitive, and even neurodynamically likely, to think of the neural processing that generates temporal experience as involving brief signal convergence culminating in discrete integration events (Lee, 2014; Gallagher and Zahavi, 2014). The insularity of these postulated (sequences of) integration events motivates an atomist picture. The third main reason is the existence of temporal illusions, cases in which experienced time and the timing of experiences seem to diverge: prima facie, a view espousing non-isomorphism between the contents of experience and the timing of experiential processes sits more comfortably with these data (Grush, 2005). The chief bone of contention here is the *apparent motion (AM) illusion*: proponents of all the major philosophical views have weighed in on it (e.g., Dennett and Kinsbourne, 1992; Grush, 2007; Dainton, 2008/2010; Arstila, 2016a), as have many neuroscientists (e.g., Adelsen and Bergen, 1985; Grossberg and Rudd, 1989; Jentzen et al., 2013; Sanders et al., 2014; Herzog and Ogmen, 2015; VanRullen, 2016).

position because they leverage latency variance to maintain resemblance of brain and experienced time. Though this alliance isn't theoretically necessary, I will be presenting a theory that honors both differential latency and extensionalism.

By developing an empirically informed neuroscience of apparent motion, highlighting mechanisms like reentrant circuitry and oscillatory multiplexing that have not generally made it onto philosophers' radars to date in this debate, I will show that extensionalists have nothing to fear from apparent motion – and, by extension, other temporal illusions. An in-depth understanding of the relevant neurodynamics shows that the ordinal phenomenology of apparent motion resembles and hence is arguably explained by the ordinal progression of oscillatory mechanisms.[12] I thereby endeavor to show that extensionalism is a viable and plausible theory of immanent temporal consciousness – i.e, the specious present (cf. Arstila and Lloyd, 2014) – despite temporal illusions and the fact that representational content determination is typically non-resemblant vis-à-vis its neural vehicles.

1.4. Argumentative Strategy

It is important to be very clear about what I will be claiming. Although I endorse an extensionalist theory of the specious present, I will not be trying to resolve the larger, more general, extensionalism-atomism debate on temporal consciousness. This is for reasons of space and methodological concern. Two concerns are foremost. One, I am doubtful that a single theory of temporal consciousness can account for the full host of very disparate temporal experiences we can have (cf. Lloyd and Arstila, 2014; Grush, 2016; Montemayor, 2017; Viera, 2019). Hence, I restrict my analysis to the specious present as previously characterized. Two, Hoerl (2017) convincingly points out some

[12] The inference from "resembles" to "is explained by" can be resisted of course, since the resemblance might be accidental or non-causal, but in the context of an empirically supported causal mechanism, it's the most natural inference, and at least shifts the burden of argument to the atomist.

serious obstacles in distinguishing between metaphysical views via empirical inquiry. Consider that while extensionalists highlight the temporal flow, extension and continuity of representational vehicles to explain the flow, extension and continuity of experiential content, some atomists have claimed they can posit a continuum of overlapping representational vehicles to account for the same phenomena (Lee, 2014; Gallagher and Zahavi, 2014). However, if that is the case, then it is unclear (at best) what empirically accessible differences might exist between the kind of extensionalism I advocate and (what we might call) an extended overlap atomism. While I think it is questionable whether the atomist can legitimately claim such features of the view without contradiction (cf. White, 2018), I do not have adequate space for that discussion.[13]

[13] What I'm thinking about here has been nicely articulated by Peter White (2018), who argues that the phenomenological continuity of conscious experience requires that consecutive experiential frames (if such there be) must have overlapping, partially integrated information – a point agreed to by atomists in general (Grush, 2005; Gallagher and Zahavi, 2014; Lee, 2014). But, "if the informational content of successive frames is integrated, then it is questionable to what extent frames can be described as discrete" (p. 119). And if they aren't discrete, then they should fail to meet the atomist's requisites. Let me briefly give some passages that illustrate the significant potential confusion. Lee writes, "…stages of a stream of atomic experiences that are close enough in time may not be completely independent metaphysical events. Dainton's [extensionalist] response is likely to be that the existence of both causal and realization connections between stages is not the same as the existence of the kind of experiential connections that he thinks exist…" (2014b; p.163). However, on any naturalistic view, experiential properties *just are* the product of causal and realization conditions of the relevant neurodynamics, so the empirical difference between views becomes indistinguishable. Lee seems to recognize this implication when he later states, "If all [atomic] experiences are extended in this way, this makes it tricky to draw a sharp line between synchronic unity and diachronic unity…" (ibid.; p.164). However, this looks like it undermines atomist views by equivocation. Along these lines he speculates that, "…even in an atomic view, total experiences at different times can overlap by sharing experiential parts…By implication, the momentary stages of an atomic stream of consciousness may not be experientially isolated islands, but may be connected to each other by a criss-crossing web of unity relations….even on an atomic view, there can be experiential connections between stages that are similar to those that appear in the extensionalist view" (ibid.; p. 165). Again, it's hard (if not impossible) to see what empirical difference could separate this (questionably coherent) version of atomism from extensionalism. As if that weren't enough, Lee holds, "…I should stress that the atomic view is also compatible with a lack of any such diachronic connections…" (ibid.). Prima facie, this is quite the case of having your cake and eating it too. This point is underscored by Grush's (per. comm., 2020) helpful reflection that, "what an atomist needs is that the atoms don't require connections of the relevant sort to be coherent stand-alone experiences. But I don't think the atomist needs to deny that they might nevertheless have such connections." This is analogous to the point that the NR-theorist can enjoy resemblance without requiring it. But this seems too dialectically good to be true. On such a liberal picture, we should all be NR-theorists and have it all. For the NR-view to have theoretical bite, I think it at least needs to admit that if the experiential connections exist, or if resemblance exists, then

Hence, my goal is to show the consonance of the ROM neurodynamical model with an extensionalist view of the specious present. I will not attempt to show that the ROM model is incompatible with atomist views. But there is still a large dialectical victory to be won! Since oscillatory approaches are typically thought to imply anti-extensionalist theories of temporal experience (cf. Ruhnau, 1995; Metzinger, 1995; Busch and VanRullen, 2014), if I can demonstrate the natural coherence of my model and extensionalism, I will have achieved my aim.

My defense of extensionalism involves a differential latency theory. Differential latency views show that stimulus timing (an objective external property) and the timing of neural processes (an objective internal property) can and do come apart. Moreover, while stimulus timing and experienced temporal order can be asymmetrical, differential latency views show how neurodynamical progression resembles the ordinality of experienced content. Baldo and Caticha (2005) provide a clear description of the strategy I will employ:

> The existence of a sequence of processing steps naturally includes intrinsic temporal delays…[that] can influence not only the magnitude of the [temporal illusion] but the very nature of the perceptual effect… This conclusion lies at the very core of the differential latencies account.…a stimulus delivered to the input layer after the presentation of a previous stimulation could be able to catch up with the ongoing neural activity produced by the preceding stimulus and modify it before its perceptual actualization (2627-8).

Work on the flash-lag illusion and color-motion asynchronies has already demonstrated the fecundity of the differential latency view (Purushothaman et al., 1998;

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the burden of proof is on the NR-theorist to explain why we shouldn't adopt a R-view as an inference to the best explanation. Given such potential confusions, widespread philosophical contortions, and the variety of different extensionalist and atomist views on the table, I will restrict my claims to establishing the consonance of my neurodynamical model and an extensionalist theory of the specious present.

Patel et al., 2000; Bedell et al., 2003; Ogmen et al., 2004; Bedell et al., 2006; Kafaligonul et al., 2010; Bachmann, 2013[14]). The present work attempts to add three features to the discussion: (1) to more deeply integrate the philosophical work on temporal consciousness with the neuroscientific approaches already on the table; (2) to provide a more detailed cortical timing model of apparent motion than has so far been given; and (3) to ground a coherent model in an oscillatory framework, a general neurodynamical framework that has ever-expanding experimental support (Buzsaki, 2006; Voytek and Knight, 2015).

1.5. Chapter Summary

Amongst those who accept the reality of the specious present, there are two basic views about the vehicle-content relation. The simplest type of theory is that the temporal representational content of the specious present is determined by the temporal properties of the representational vehicles during the specious present. This is the simplest view because once one understands the relevant temporal properties of the relevant neural vehicles – what Lee (2014) describes as the "core realizer" – one can infer the details of

[14] Generally speaking, as differential latency accounts, these approaches are typically not at odds with that given here. To cite perhaps the most critical example to my mind, Bachmann's (2013) perceptual retouch theory explains the accelerated processing of subsequent (as opposed to initial) stimuli on account of the fact that the processing of the first stimulus through an initially sluggish thalamic system ignites the thalamic system (i.e., the stimulus-relevant sub-nuclei and thalamic reticular nuclei), which then processes subsequent modality- and location-relevant stimuli more quickly as a result. Such a view helps explain the flash lag and Frolich effects, among other illusions (Bachmann, 2013), and does so in a manner that is entirely complementary to the cortically-based mechanisms I describe below. The (ROM) model I present describes the structure of hierarchical circuits supporting consciousness without anatomically defining that hierarchy. Since thalamocortical processing integrity is well documented to be a necessary condition for conscious awareness, the full development of the ROM model will include thalamocortical integration (among other anatomical regions). Hence, an integration of a subcortical differential latency model like Bachmann's (which I fully endorse) with that provided here is very natural, but must be reserved for a future publication.

temporal content. Call such theories R-theories, for positing that the temporal representational content of the specious present *resembles* the timing of the vehicular dynamics constituting the core realizer *and is explained by that resemblance*.

Contrast R-theories with non-resemblance theories (NR). NR-theories deny that the explanation for the temporal representational content of the specious present *directly* adverts to the temporal properties of vehicular dynamics. A basic motivation for NR-theories is that it is implausible to think that representational contents resemble their vehicles for most types of content. Paraphrasing a suggestion by Rick Grush, even if the brain is gray, is this a legitimate explanation for why and how the brain represents the color gray? By parity of reasoning, why assume that because brain states progress through time it is that fact that explains an experience of events progressing through time? This reasoning shows that there isn't a prima facie bias in favor of R-theories. Cases of temporal illusion, moreover – in which the order of objective events seems to conflict with the order in which events are subjectively experienced – arguably make NR-theories the received view in the philosophy of temporal perception.

The project of this dissertation, then, is to articulate a detailed picture of the vehicular dynamics that plausibly generate the temporal representational content of the specious present and then argue that the presented model is best construed as an R view. As mentioned, the detailed picture is ROM theory. The proof of principle will be showing how ROM theory can handle temporal illusions – like apparent motion – in an R-theoretical manner (ch 4).

The outline for this dissertation is the following. In chapter 2, I introduce the key features of the extant theories of temporal consciousness, focusing on the theories of extensionalism, atomism, retentionalism, the Trajectory Estimation Model, the memory cinematic view and The Simple View. My goal there is to give enough explanation and structure to allow the reader to follow the discussion in chapter 3. Chapter 3 turns to the core test case of this dissertation, apparent motion. There, I will trace the historical debate between the aforementioned theories and then examine the sufficiency with which the key theories attempt to account for apparent motion.

It is only in chapter 4 that I will present a new theory of apparent motion, one that falls out of a larger theoretical framework, ROM. In chapter 4, I focus on how a differential latency view coupled with knowledge of empirically-generated latencies shows apparent motion is best explained in terms of an extensionalist theory – the specific commitment of ROM. That leads me to chapter 5, where I unpack the full, general theory of ROM, reentrant oscillatory multiplexing. There I explain the mechanistic workings of ROM, and then turn to how it explains a host of features of the specious present in an extensionalist manner, most especially the phenomenological continuity and representational discontinuity that a full theory of the specious present must explain.

After presenting the general framework, I turn to objections to ROM in chapter 6. These include a number of objections from both neuroscience and philosophy. Specifically, from a neuroscience point of view, I'll consider objections based on the latencies used by the model, the circuits employed by the model, whether absence seizures are a counterexample to ROM, and whether an oscillatory framework implies ROM is not an extensionalist theory after all. Philosophically speaking, I'll look at objections based on ROM's extensionalist commitment and objections based on ROM's endorsement of the specious present concept.

The dissertation concludes with chapter 7: a look forward to various ways in which this work and the ROM model intersect with independent developments in philosophy and science, hinting at its more general significance as a theoretical position. Specifically, I consider the nature of ROM's theory of representation, its relation to extant neurobiological theories of consciousness, its relation to models of timing adduced by neuroscientists, and finally how it comports with predictive processing models. References follow.

CH. 2: Philosophical Theories of the Specious Present

2.1. Overview of Theoretical Positions

As I will classify it, there are two main types of theories that accept the specious present, resemblance (R-) and non-resemblance (NR-) theories, and a main class of theories, "cinematic," that reject the specious present, but still attempt to account for, and explain, the phenomena that the concept of the specious present was designed to accommodate.[15] I will look at characteristic variants for each of those three theoretical classes. I am not attempting to provide an exhaustive list, but rather a description of the critical features of the most discussed views – enough to follow the ensuing discussion. I'll begin with a commitment all theories have in common:

(1) Phenomenological flow: Immediate temporal experience flows in such a way that its boundaries are not transparent.[16]

(1) formalizes the idea of the subjective continuity of phenomenal consciousness, which all discussants interested in immediate temporal consciousness agree upon. And they should, give its introspective undeniability. We all experience time to continuously

[15] Arstila (2016) describes his cinematic view, The Simple View (TSV), as an R-theory, but I think that unnecessarily muddies the dialectic waters. Although he posits a resemblance relation, it is more perspicuous to put a clean genealogical divide between theories that accept the specious present (R- and NR-) and those that don't (cinematic). At least, that is the way I will carve up the disputed territory in this dissertation.

[16] See Rashbrook-Cooper (2016) for an extensionalist defense of this idea.

flow. R-theorists explain it in terms of continuous representational vehicles. NR-theorists explain it in terms of vehicles that realize continuous content. And cinematic theorists explain it in terms of special faculties that present phenomenological continuity without requiring representational breadth. This is the only axiom that all theories have in common, but R- and NR- theories also share the following:

(2) Specious Present: Immediate temporal experience always represents temporally extended content.

Both R- and NR- theorists take our experiences of change and motion at face value and infer from them that our experience of the "now" is not an instantaneous one, but rather always filled with extended content (even if brief). The fact that we cannot experience instantaneous contents is direct evidence for the specious present doctrine, theorists of both stripes hold (James, 1890). But at this point, defenders of R- and NR-theories part ways. While the R-theorist attempts to account for the temporal features of immediate experience in reference to vehicular processes that resemble such features, the NR-theorist claims that there is no explanatory connection between the temporal properties of representational vehicles and the temporal properties of immediate experience. As mentioned, cinematic views reject (2). Let's look at the specifics of each theory.

2.2. Overview of R-theory (Extensionalism)[17]

It makes sense to begin with R-theory, as it is arguably the easiest to understand. R-theories explain temporal perception in the specious present by positing that experiential time (time as subjectively experienced) *resembles* brain time (objective temporal relations between neurons/neural circuits, etc.) *because* the former *is grounded in* the latter. In more technical parlance, we can say that the temporal representational content of the specious present is explained by the temporal properties of its vehicular realizers; it is the objective nature of brain time that determines and thereby explains the nature of experienced time. Since experienced time is explained by resemblance to brain time, it is natural to call these R-theories.

The upshot is R-theories give you a very straightforward explanatory story, as Dainton (2014) points out. He calls it one-dimensional in the sense that there is just one stream of experience to account for. This is in contrast to the two-dimensional theories of non-R theories, which require complex temporal representational structures at each distinct moment (p. 104). There is another sense in which the one- and two-dimensional structures obtain. R-theories explain the specious present by isomorphic vehicular dynamics. Non-R theories require a special account of how time is added to other representations; that is, they require a theory of time-stamping or time-marking. More on this below, but the general point is that R-theories are theoretically simpler accounts and this is typically construed as a value added.

[17] In this manuscript, I will be simplifying discussion by reserving the label "R-theory" for extensionalist views. Technically, cinematic views are typically based on resemblance (instantaneous), but I think it's cleaner to separate specious present views from views that reject the specious present.

So, for example, if we experience A and B as simultaneous, then R-theories explain the experience of simultaneity on account of simultaneity in the brain activity realizing representations of A and B. Alternatively, if A is experienced before B, then the brain activity realizing A precedes that of B, or so the R-theorist holds. In both of these cases, the distinctions (simultaneity and succession) are binary, so the resemblance isn't scalar but absolute. That is, something either is or is not simultaneous; an event either does or does not involve succession. But if these temporal phenomena are binary in this way, this takes us from resemblance to isomorphism because the resemblance is complete: the vehicular realizers either are or are not simultaneous or successive. It is thus commonplace to find discussions of R-theories couched in terms of an isomorphism requirement. We can formalize this by stating the second feature of R-theory as

(3) Temporal isomorphism: Temporal content is isomorphic to the temporal profile of its vehicular realizers (Dainton, 2008).

The first two principles help explain the implicit connection between R-theory and "extensionalist" theories: it is the extension of vehicular realizers (3) that explains the extended content assumed in axiom (2). Putting (2) and (3) together also gives us a further axiom (4). If R-theories explain temporally extended content through isomorphism, then the correct way to think about the specious present is through temporally extended intervals, not instants. We can formalize this with

(4) Intervallic individuation: Temporal representational content is properly characterized in terms of intervals, not by instants (Phillips, 2014).

As Hoerl (2009) puts it, "experiences can't be sliced arbitrarily finely" (p. 10). In other words, there is a minimum content represented in consciousness, and that minimum is representationally unified, such that the representational content at an instant depends on a surrounding interval of content. (4) is a strong axiom, since we normally think of intervals as being comprised of an accumulation of instants. In science and in quotidian life, the punctate instant is often thought to be metaphysically more basic than the interval. (4) reverses this idea for temporal representational content: the temporal representational content at an instant derives from an extended stretch of temporal representational content. As we'll see in the next chapter, (4) plays an important role in adjudicating some of the disputes between R-theorists and NR-theorists.

Looking over axioms (1)-(4), which summarize the key features of extensionalist views[18], we can see that the primary motivations for extensionalism are twofold: phenomenological and theoretical (Dainton, 2014). Phenomenologically, R-theorists hold that it is self-evident that a specious present exists and essentially involves an experience of temporal extension and flow (Rashbrook-Cooper, 2016). R-theories are commonly argued to have an easier time handling the phenomenological continuity and smooth flow of temporal passage we experience (Hoerl, 2013; Phillips, 2014; Rashbrook-Cooper, 2016; and see Hohwy (2016) and Wiese (2017) for arguments that the key NR-theory cannot handle these explananda.) Parsimoniously, it is worthwhile to investigate

[18] All extensionalists share a commitment to (1)-(4). There are more debatable properties, like overlap and delay, which will be – and are much more appropriately – discussed in the next chapter.

if these representational contents are due to resemblant temporal properties of relevant representational vehicles (e.g., the temporal extension and flow of the realizing neurodynamics). As mentioned, theoretically positing an isomorphism between vehicles and contents is the simplest explanation for temporal consciousness, which R-theorists can and do consider a merit of their views (Dainton, 2014). This is because the theoretical simplicity adds an explanatory fecundity: once the objective features of the realizers are understood, the subjective features of temporal consciousness can be immediately inferred.

As mentioned, the recognized name for R-theories in the literature is "extensionalism," which has a number of defenders, the strongest contingent of which might be coined the "British school" (Dainton, Hoerl, Phillips, Rashbrook-Cooper, e.g.). Basic extensionalist views hold that both vehicles and contents unfold over time and that the extension of the former explains, through resemblance, the temporal character of the latter (Hoerl, 2009; Dainton, 2008/2010; Phillips, 2014; Rashbrook-Cooper, 2016; Montemayor, 2017).

There are a number of ways in which temporal contents and vehicles might be related by resemblance. Thus, there are a number of ways extensionalism could be cashed out. The most well-discussed of these include the following:

(i) Simultaneity: Simultaneous vehicles give rise to the experience of simultaneity.

(ii) Temporal-order blindsight: Succession of some vehicles (those responsible for representing that two stimuli were non-simultaneous) conjoined with the simultaneity of other vehicles (those responsible for introspecting the actual order of the stimuli) gives rise to the experience of stimulus succession but without the ability to indicate stimulus order.

(iii) Ordinality: The order of vehicular dynamics gives rise to a resemblant order of experience.

(iv) Flow/Continuity: The flow/continuity of vehicular dynamics gives rise to a resemblant continuity of temporal experience.[19]

(v) Extension: The temporal extension of vehicular dynamics gives rise to a resemblant temporal extension of experience.

(vi) Duration: The duration of vehicular dynamics gives rise to a resemblant experience of duration.

This dissertation will concern itself with all of the foregoing (i-vi). Figure 1 illustrates the extensionalist position.

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[19] Nb. I will use flow and continuity interchangeably.

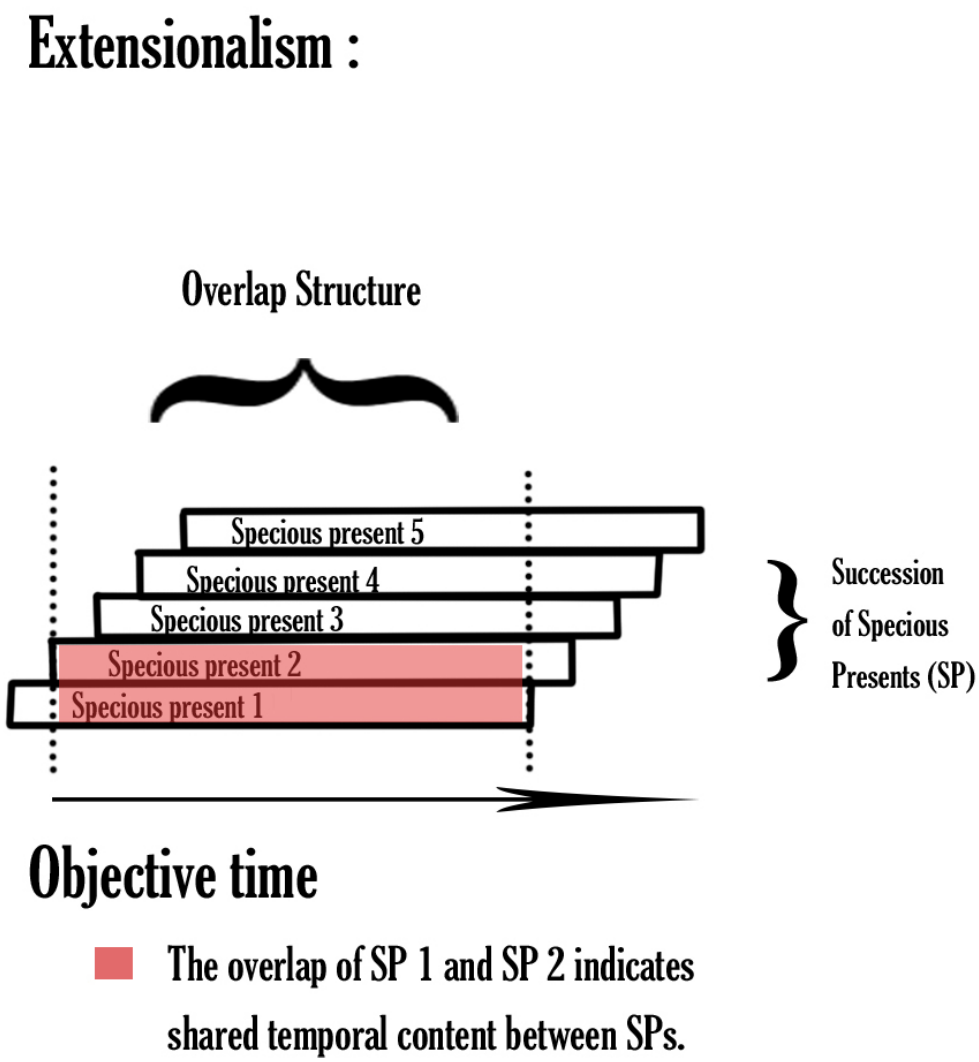

Figure 1: The classic overlap extensionalist view (see ch. 3 for a full discussion).

2.3. Overview of NR-theories

NR-theories hold that, however neural vehicles generate temporal content, the temporal properties of the relevant representational vehicles do not explain the temporal properties experienced during the specious present. Hence, NR-theories require an additional account of how temporal content is generated (since it isn't generated intrinsically by vehicular dynamics). Typically, the addition of temporal content is likened to a time-stamp or time-marking process. Different NR-theories forward different accounts, but they all share the idea that time is an additional representational content added to, or combined with, other representational contents.

In favor of NR-theories, three general arguments are typically adduced. Lee (2014) argues that for properties to be representationally connected (if A is experienced as following B, then the representations for A and B are temporally connected, e.g.) requires that they are simultaneously present in the vehicular machinery that generates representational connectedness, temporal relations included. The upshot of this argument is that even if we represent various events as occurring in temporal succession, it still requires temporal simultaneity from the point of view of brain time. This obviously instantiates a non-resemblant vehicle-content relation.

A second argument for NR-theories comes from Busch and VanRullen (2014), who argue that neuroscience strongly supports the view that continuous temporal perception depends upon oscillatory dynamics that are discrete and discontinuous. Since continuous temporal representational content is argued to depend on discontinuous vehicular dynamics (oscillatory cycles), this is an example of non-resemblance.

Finally, a third family of arguments for NR-theories has been most influentially championed by Rick Grush (2007; 2015), who has drawn a good deal of attention refining and extending Dennett and Kinsbourne's (1992) claims that temporal illusions show that the order of processing in the brain is different from the order of experience. In the case of apparent motion, for example, if the brain needs to process two stationary signals in succession (A then B) to create the experience of A moving towards B (A -> B), then the timing of processing, in which A and B must both be processed to create the experience of apparent motion, is non-resemblant with respect to an experience that begins with A moving towards an unknown endpoint B. Temporal illusions leverage the idea that for the brain to create these illusions, it must already have processed and integrated information from multiple external sources. The paradox is that the temporal properties of brain processing do not resemble time as represented. More on this in the next chapter, but this will hopefully serve as an introduction.

The upshot is that all of these views are unified in taking various observations about brain dynamics to reveal non-resemblance between explicit temporal content and the temporal nature of vehicular dynamics.

NR-theories hold that the explanation for temporal content is not found in vehicle-content resemblance. Instead of temporal content being inherited from the temporal properties of the vehicular realizers, NR-theories posit that temporal representation is a unique type of mental representation that in conjunction with other types of mental representation generates the rich content of the specious present. Dennett and Kinsbourne (1992) describe it as a time-stamp or time-marker view because temporal representation is "stamped" onto other representations (color, shape, sound, etc.) to indicate the temporal properties they are experienced to have (Arstila, 2015). In the same way that the dates stamped onto letters need not resemble the order in which they are received (but nevertheless indicate the actual temporal order in which letters were shipped), so too is it unnecessary (and perhaps usually unlikely) that the temporal stamping of perceptual representations corresponds to the temporal features represented in experienced time.

A prima facie objection to "time stamp" views may be that if time is an add-on representation, then it should be possible to experience atemporal representations (just as, e.g., color is an add-on representation as illustrated by cases of colorblindness). However, introspection provides no evidence of atemporal representation (James, 1890; Stern, 1897; Pelczar, 2010). In response, the NR-theorist can – and perhaps must – claim that temporal representation is a necessary, but distinct, component of perceptual representation. This saves the NR-theorist from phenomenological implausibility.[20]

Importantly, NR-theories would not be refuted by vehicle-content isomorphism because the NR-theorist can always claim that such isomorphism is *explanatorily tangential*. In practice, causal interventions along the lines of transcranial magnetic stimulation (TMS) may be able to settle the matter, but such lengths are probably not required to tilt the presumption of plausibility because, in practice, most NR-theorists espouse views according to which the temporal properties of vehicles – even if not instantaneous (Lee, 2014) – are significantly shorter than the temporal content represented. For example, Rick Grush's (2005; 2007; 2016) trajectory estimation model (TEM), the most developed and most integrative NR-theory, posits that temporal contents come in intervals of varying lengths, averaging around 200-300 ms perhaps, but are created by neurodynamical events of much shorter duration, perhaps around 20ms.[21]

[20] A good example of this strategy is Rick Grush's (2005) Trajectory Estimation Model (TEM), in which temporal representation is a necessary but distinct component of perceptual representation. On such views, all perceptual representation has a temporal component, but that component is generated in a manner in which vehicular time does not determine or explain experienced time. More on this below.
[21] Grush takes no firm stand on how long the vehicular events are, but he has used 20ms (2005; 2016). His estimation of the duration of the specious present, though, is not ad hoc. 200-300 ms is the duration

The TEM combines features of the other NR-theories, atomism (Lee, 2014; and see Rashbrook-Oliver, 2015m, for discussion) and retentionalism (Gallagher and Zahavi, 2014; and see Dainton, 2010, for discussion). These theories can be broad-brushed as follows: Atomism (i) rejects temporal isomorphism and (ii) adverts only to *perceptual* mental states. Retentionalism (iii) incorporates the idea that the construction of time by the brain includes non-perceptual states (Grush, 2016). And the TEM enshrines (i) and (ii) within an emulation theoretic umbrella.[22] Hence there are three views of note, and I will look at them in overview, in order of increasing complexity.

2.3.1. Atomism[23]

Atomism is the NR-theoretical view that the vehicular dynamics realizing the perceptually-defined specious present are themselves functionally atomic. Here, the perceptual can be contrasted with the explicitly conceptual. There is a large literature and debate on the difference, but a useful gloss is the following: conceptutalization involves the categorization of perceptual states. Whereas perception involves experiential

implicated in a number of experimental paradigms, from attentional blink and inhibition of return to latencies of ERP measures correlated with transitions to conscious representational content (e.g., the visual awareness negativity and the late positivity, fall within this range (cf. Dehaene and Changeux, 2011; Arstila, 2015)). Further, this scale is an important interval for considering the latencies of sensory and motor processing (Grush, 2016).

[22] It is worth noting that in contrast to the TEM, actual retentionalist views employ as "components" non-perceptual mental states. Although it isn't entirely clear how to understand the exact nature of these non-perceptual mental states (Dainton, 2010), it is clear that retentionalism is strictly at odds with atomism (because confined to perceptual mental states).

[23] Technically, Lee (2014) calls his view 'extended atomism' due to his recognition that neural vehicles subserving temporal representation are objectively extended in time. I do not include this as an axiom as it is perhaps universally assumed. I use the shorter label for convenience and consonance with most discussion in the literature.

particulars, conceptualization involves forming generalizations over those particulars. Atomism is a view that applies to only perceptual states:

(5) Perceptual content: immediate temporal experience is perceptual in nature.

Atomism is perceptual in that the temporal experience captured under its aegis doesn't require explicit conceptualization. More importantly, regarding debates in temporal perception, there are various postulations for explaining temporal experience in terms of non-perceptual mental states. The retentional view (below) will highlight a few of these. For now, it is sufficient to say that the key sense of perception motivating atomism contrasts with memory or memory faculties. A number of theorists (Reid, Husserl, Le Podevin, etc.) explain temporal experience in terms of both perception and memory. Atomism rejects this. Atomism is a theory of a kind of temporal experience independent of any explicit memory states or faculties.[24]

This brings us to atomism's commitment to functional atomism. Lee (2014) argues for this with his "simultaneity" argument, the central idea of which is that for the brain to represent content in a temporal relation of any kind (and hence generate temporal content simpliciter), the corresponding representations must be simultaneously present within the representational machinery. And if temporal representation is generated by vehicles that are functionally simultaneous, then there is no functional extension of those

[24] This is also a landmine area of debate: the line between perception and memory. The problem is that perception itself seems to require the storage and maintenance of information for non-trivial durations. Perhaps the debate can be waged over the difference between storage (memory) vs. maintenance (perception). It's a debate I'll leave here though.

vehicles to contribute to their individuation (cf. Rashbrook-Cooper, 2015m). Thus we have:

(6) Atomic individuation: the temporal extension of vehicles does not imply temporal content relies on, or is explained by, temporal extension.

(6) enshrines the atomist commitment that time does not code for time – a hallmark commitment of NR theories in general. So even though Lee (ibid) is committed to extended vehicular realizers of the specious present, his argument is meant to show that the computational explanation for temporally extended representational content is tangential to the brief temporal extension of vehicular dynamics. Lee's simultaneity argument is discussed in ch. 6. The general atomist position is illustrated in figure 2.

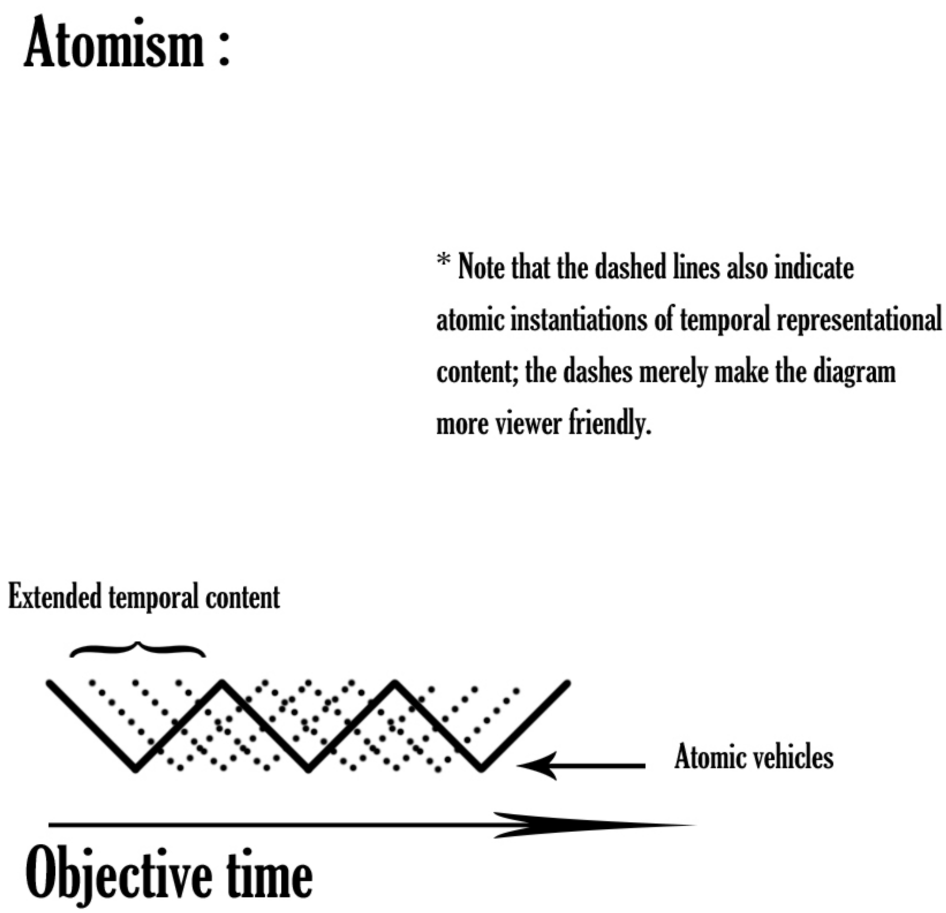

Figure 2: The Atomist theory of the specious present.

2.3.2. Retentionalism

Retentionalism has a long-standing tradition in temporal perception, characterizing aspects of the views of James, Husserl and Broad among other seminal writers (Dainton, 2010; p. 78). It is the seminal NR-theory of the specious present. The retentionalist posits a three-fold structure to account for the specious present. The intersection of the just-passed and the about-to-be is the present, strictly construed, and is an instantaneous act of apprehension (Gallagher and Zahavi, 2014). This is dubbed a primal impression (ibid).

(7) Primal Impression: a momentary consciousness of a "now" or current phase of an object or change.

By itself, primal impressions would be but knife-blades, to borrow James' phrase, and could not furnish a sense of temporality. For this, primal impressions must be contextualized by consciousness of the immediate past. Husserl calls these "retentions" (Mensch, 2014).

(8) Retention: consciousness of the just-passed horizon of what is experienced.[25]

To account for our self-evident experience of temporal extension and continuity, retentionalists explain that momentary conscious awareness is contextualized by retention of what has just-passed. It is this retention that provides necessary context to the momentary apprehension of the primal impression that allows for the realization of temporal experience. Retentions are memory-like mental states, but they are different

[25] Gallagher and Zahavi (2014) argue convincingly that Husserl's account cannot be fractured in the way suggested here – i.e., experience only obtains in virtue of the conjunction of the retention-primal impression-protention structure and cannot be satisfactorily discussed in terms of "experience" in independent terms. Specifically, primal impressions cannot furnish a sense of experience without already being contextualized by retentions (p. 94). If this is correct, which I endorse, then my division of these axioms has to be understood in light of the fact that they can't be understood piecemeal but rather as interdependent parts of a complex theoretical system.

from memories in that they are experienced as the just-passed edge of the present, but not truly as past, as per actual memories (Grush, 2007). Additionally, momentary consciousness is contextualized by anticipation of the about-to-be. Husserl calls these protentions (Mensch, 2014).

(9) Protention: consciousness of an anticipated future.[26]

Protentions are the future-looking converse of retentions and explain how we experience, for example, a chord resolve slightly before and certainly as it is occurring. Again, both retentions and protentions are non-perceptual. Given that they are memory-like, but not memory states, and perceptual-like, but not perceptual states, it is no wonder that there has been such confusion interpreting and explaining what they really denote (Dainton, 2010). The suite of retentions and protentions can be summarized by a further axiom:

(10) Non-perceptual mental states: temporal experience of the specious present requires non-perceptual contents (i.e., retentions and protentions).

Note that axioms (8)-(9)-(10) strongly differentiate retentionalist and atomist theories, as they all involve non-perceptual states. A final axiom differentiates retentionalist views from the TEM (to be discussed next). Retentionalism characterizes temporal character in terms of past, present and future states, which Grush (2016) labels

[26] NB. Not all Retentionalist theories recognize protention.

"A-ish" content in distinction to describing temporality in terms of earlier-than/simultaneous/later-than, which he labels "B-ish." By way of foreshadowing, the main difference is the scale of applicable temporal discrimination. B-ish content can be applicable on scales at which the A-ish concepts don't make sense. A good example is what I've called "temporal-order blindsight," which is where a subject can discern ordinal asymmetry of stimuli without being able to discern stimulus order. The A-ish theorist is a little uncomfortable here, because temporal order blindsight doesn't seem to involve any just-passed contents: everything seems to happen at once. But from a B-ish content point-of-view, it makes sense how the subject can attest to non-simultaneity without being able to accurately report order. Returning to Retentionalism, we can add the following final axiom:

(11) A-ish content: temporal experience involves a tensed reference frame (past/present/future) because it is within the intersection of the just-past with the about-to-be that the specious present achieves temporal dimensionality (Gallagher and Zahavi, 2014).

The basic motivation for retentionalist views is to accurately account for the temporal extension of all conscious experience in a way that captures the richness of temporal experience and the inherent temporal structure of consciousness (Mensch, 2014; Gallagher and Zahavi, 2014). The special theoretical apparatus of retentionalism was designed to harmonize the phenomenology of consciousness being a succession of near instantaneous "now" moments with the concurrent consciousness of those moments being imbued with a sense of temporal extension (Grush, 2007; Dainton, 2010; Hoerl, 2013). I turn to the most complex NR-model in the philosophy of temporal perception literature.

2.3.3. Trajectory-Estimation Model

Rick Grush's TEM is the state of the art in NR-theories (Dainton, 2010; Molder, 2014; Lee 2014; Arstila, 2015). It is a complex theory based on what has been one of the most important ideas in 21st century philosophy: that the cognitive economy is a predictive engine (cf. Grush, 2004; Rao and Ballard, 1999; Llinas, 2001). It is therefore an explanation for temporal perception cast in the spirit of increasingly influential generative models (cf. Friston, 2005; Hohwy, 2012; Clark, 2013).

Its basic postulation is that the brain produces a model of the world to guide action (broadly construed) by predicting/estimating stimulus trajectories (and not instants). The subject experiences the content of those estimates, and not necessarily objective reality. In order to minimize asymmetry between internal representation and action, on the one hand, and the exigencies of external reality, on the other, the TEM describes an algorithmic[27] process of continual readjustment based on comparisons of past and current internal states that serve as proxies for environmental states (including present such states representing future such states) with that of past and current stimulus

[27] David Marr (1982) provided a useful tripartite deconstruction of vision (and by extension other cognitive processes): a computational level that is characterized by a problem to be solved (e.g., find food by color); an algorithmic level that describes the abstract rules that solve the problem (e.g., differentiate colors and assign colors to foods); and an implementation level that explains the physical realization of the algorithm (retinal cones + parvocellular signals + V1 + V4/V8, e.g.). Grush's TEM is outstanding in that it is the first full-scale algorithmic model of how temporal representation can be algorithmically structured by brains; however, it doesn't offer a model of the relevant neural realizers. The ROM theory attempts to go a step further and justify a view of the specious present based on empirical evidence for the relevant implementation-level details of cortical neurodynamics.

registrations in order to optimize current and future behavior. These continual readjustments allow for generally accurate environmental prediction and action. The actual details of Grush's TEM include some fancy machinery, and are unnecessary at this stage of discussion, but Hohwy (2016) does a nice job of summarizing the main ideas behind the model:

> Grush's Tajectory Estimation Theory treats perception in terms of Kalman filtering. A Kalman filter is a control tool for estimating noisy causes of sensory input and becomes a form of Bayesian inference where estimates are weighted by their signal-to-noise ratio (cf. Kalman gain)… [The three aspects of Grush's theory]…are filtering (Bayesian weighting of priors and likelihoods); prediction (generation of future states of the domain in question); and, smoothing (comparing past predictions with actual past posteriors). (p. 328)

The products of all this algorithmic machinery, as mentioned, are trajectory estimates that correspond to a retrospectively- and prospectively-imbued temporal perception encompassing around ~200-300 ms of representational content. Each extended representational trajectory is produced by relatively instantaneous (~20 ms) vehicular dynamics. The temporal perception experienced involves what Grush calls "B-ish" temporal content – as mentioned, a kind of temporal content captured in terms of earlier-than/simultaneous/later-than concepts. In comparison to A-ish content, Grush's TEM is designed to only explain the "now" (strictly present) part of experience. Thus, in what follows, I will characterize the TEM by its aspiration to correctly account for "minimal temporal experience" – the briefest introspectively available experience.

Though these brief trajectories always produce intervallic content, the content can be "overwritten" in the case that a better interpretation of the environment becomes available. This involves a retrospective revision that harmonizes what must have just happened based on current input. The possibility of experiencing inconsistent successive temporal contents is forestalled, however, because the mechanism operates on a time scale so brief as to preclude consolidation into memory.

Since the temporal content generated spans an interval, the TEM can explain the experience of temporal extension. Moreover, the fact that trajectory estimations are based on revision and prediction in the service of coherent experience, interpretation and action explains the selective advantage that systems that process trajectories (instead of instants) would enjoy. Summarizing, the main commitments of the TEM are the following:

(12) Perceptual content: minimal temporal experience is perceptual.

(13) No delay: minimal temporal perception is not delayed.

(14) B-ish temporal content: minimal temporal content is best expressed by the concepts earlier-than/simultaneous/later-than.

(15) Trajectory structure: minimal temporal perceptual content covers trajectories/intervals.

(16) Temporal contextualization: perceptual trajectories typically include earlier and later phases, enabling postdiction and prediction.

(17) Overwriting: subsequent trajectory estimations can overturn prior estimations and 'overwrite' the experiential narrative content trajectory for greater adaptive coherence.

The main motivations for the TEM are arguably threefold.[28] First, to provide an algorithmic account of minimal temporal perception that is consonant with evolutionary neuroscience (e.g., predictive models). Second, to capture the retentionalist idea that minimal temporal experience is both backward and forward-looking (but note that it shares the atomist structure of figure 2). Third, to provide a theory to optimally account for temporal illusions. Grush's model has perhaps inspired more ink than any other theory of temporal perception (Molder, 2014; Arstila, 2015), and it will be a focal point in the next chapter.

2.3. Overview of Cinematic theories

Cinematic theories are characterized by their rejection of the specious present doctrine. I include them here for completeness. In chapter 6 I will present some arguments in favor of rejecting this class of views, but I restrict myself here to providing the general picture. The main feature of such theories is their commitment to instantaneous content instead of the extended temporal content espoused by specious present theories. Since they hold that representational content is confined to instantaneous snapshots, cinematic theorists have to find special ways to account for the direct experience of motion. All cinematic theories share the following basic structure:

[28] Interestingly, it may be that the TEM is not in conflict with extensionalist accounts of longer durations where temporal continuity and flow are the defining phenomenological data, instead of temporal illusions at the liminal border of perception.

(18) No delay: Experience occurs as soon as processing reaches a perceptual end point. There is no delay.

(19) Temporal isomorphism: Experience occurs concurrently to the relevant neural activity; it is an "online" phenomenon.

(20) Instantaneous content: The content represented in experience has no temporal breadth.

There have been two distinct kinds of attempts to explain the experience of temporal extension within the confines of a theory that espouses instantaneous contents: memory theories and pure phenomenology theories. Both kinds of theories accept the aforementioned assumptions (18)-(20) and then add distinct additional premises. In short, memory theories account for experiences of motion by memory faculties, while pure phenomenology theories do so by citing encapsulated perceptual mechanisms that allow the divorcing of temporal experience from temporal representation, traditionally understood.

2.3.1. Cinematic Memory theories

Cinematic memory theories explain the experience of motion as the result of a special inferential process that occurs when an instantaneous perceptual snapshot is compared via memory faculties to prior perceptions (Reid, 2002). Le Poidevin (2007) outlines the most cited modern version of the view. In addition to the foregoing 3 tenets, cinematic memory theories add the following:

(21) Memory content: The comparison of different perceptual snapshots via the memory faculty results in an inference of motion.

The main motivation for such views is to embrace the common sense idea that perception is essentially an immediate and instantaneous experience. Memory plays an integrative role on this view, stitching together various instantaneous perceptions into a representational tapestry that gives the illusion of motion through *inference*. This is distinct from retentionalist views for a few reasons. First of all, cinematic views hold that instantaneous perception and experience is possible without memory, but that without memory temporal extension can't be experienced. Retentionalist views, on the contrary, distinguish primal impressions and retentions theoretically but not in practice; that is, for the retentionalist, these distinctions do not correspond to functionally separable mental faculties. As Grush explains, "Husserl took the whole structure to be a model of perception" (per. comm.). They are separable in description, but not in operation (Husserl, 1911; Zahavi and Gallagher, 2014). Secondly, then, while it is possible to have punctate experience on a cinematic memory view – where memory faculties are absent – all experience is temporally extended on retentionalist views. A contrasting, more modern, view is that there are local neural mechanisms that play that integrative role.

2.3.2. Pure Phenomenology theories

Valtteri Arstila develops this view in his (2016) paper, where he attempts to provide what he characterizes as the simplest theoretical position possible. "The Simple View" (TSV), as he calls it, accounts for the experience of motion by positing the existence of special encapsulated neural mechanisms that can generate the experience of motion without violating instantaneous representational content. That is, he claims that the experience of motion is generated independently of representation-realizing processes. His strategy can be formulated by adding the following two tenets to the abovementioned (18)-(20).

(22) Dynamic snapshot view: Instantaneous content can create the phenomenology of temporal extension through 'pure phenomenology.'

(23) Nonlinear latency difference view: Apparent violations of vehicle-content isomorphism can be explained by understanding that recurrent activity is needed for temporal perception and also biases subsequent stimuli processing.

The idea behind (23), in the context of AM, is that there are different circuits required to generate apparent motion, and that the latencies of such circuits are distinct, permitting 'nonlinear' processing of stimulus properties. Hence, certain stimulus properties (motion) can be processed more quickly than other properties (detailed location) on account of differences in the latencies of the circuits that process such properties. So even if location information begins to be processed first, the fast-tracking of motion information will affect the representation of location and even allow motion to precede location information in some contexts.

The idea behind (22) is to account for temporal phenomenology without temporal extension. To accomplish this, Arstila plumps for the idea of 'pure phenomenology,' which is the concept that one can experience movement without the explicit representation of movement. Arstila's key example is 'pure motion,' and he uses the waterfall and rotating snakes illusions as examples of how one can experience motion without representing motion.

TSV has two strong theoretical merits. First, there is its theoretical simplicity: It is an attempt, at least, to formulate the simplest relation between vehicles and contents that does justice to our experience of temporal extension. Secondly, aspects of it enjoy empirical plausibility: there is good evidence for axiom (23) (see chapters 4 and 5). TSV has more implementation-level empirical support than any other theory of apparent motion (bracketing ROM-theory for the time being). The only view on a par in terms of detail is Grush's TEM, which has some robust empirical support as well (2005), largely at an algorithmic level, though. Figure 3 illustrates the TSV vehicle-content structure.

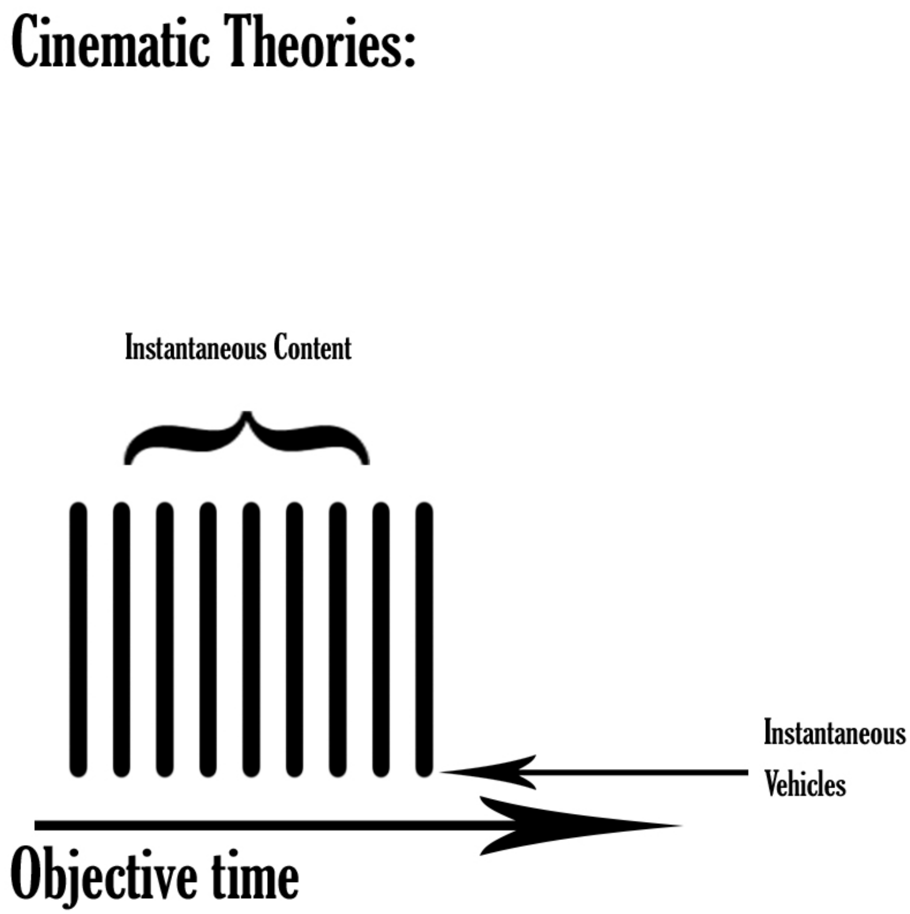

Figure 3: The cinematic TSV structure.

2.4. Looking Ahead: Relation of ROM-theory to Other Views

ROM theory defends a unique neuroscientific account of temporal content realization. Philosophically, it involves a defense of an extensionalist account of the specious present, but using, among other things, a differential latency account (similar to

TSV). And congruent with atomism and the TEM, among other views, ROM is leveraged here as an explanation for temporal perception.[29] Thus, ROM theory is a novel philosophical contribution to the vehicle-content debate on temporal experience. Having looked at some basic philosophical positions on the specious present, I turn to their accounts of apparent motion.

[29] It shouldn't be assumed, however, that ROM's explanatory merits are limited to purely perceptual experiences. Its basic structure supports network integration that would support conceptualization as well. (See chapter 5).

Chapter 3: Historically Antecedent Debates of AM

3.1. Introduction

The aim of this chapter is to canvas the historical discussion of the classic empirical test case for adjudicating between the theories of temporal experience. For three related reasons, the optimal test case is perhaps apparent motion (AM). One, it is a phenomenon about which a fair amount is scientifically known. Two, it has arguably received more philosophical ink than any other temporal illusion. And three, most importantly, theorists with rival positions take apparent motion to be best explained by their view. Specifically, Rick Grush, following Dennett, takes it as the primary illustration of temporal vehicle-content asymmetry and hence justification of an NR-theory, while Barry Dainton defends an extensionalist reading of the phenomenon, and Arstila introduces his Non-Linear Latency Difference view to account for the results on behalf of TSV. According to Dainton's (2010) taxonomy of the temporal experience debate into extensionalist, retentionalist and cinematic theories, every camp of the debate claims to preferentially explain apparent motion. Adjudication is needed.

I will wait for chapter 4 to explain the ROM view of AM. My aim in this chapter is to introduce the prior discussion and to offer some reasons to look for a new perspective. While I will be critiquing the extant views of temporal perception and their models of AM, I do not rest too much on it. My ultimate goal is relatively straightforward: to provide a novel, neuroscientifically-informed alternative to extant accounts while shifting the burden of argument to rival views.

3.2. The Apparent Motion Illusion

If you flash two spatially proximate lights (A&B, say) rather quickly in succession (Wertheimer (1912) found that 60ms is ideal), an observer does not see two flashes but perceives a single light moving from A to B. Roughly following Braddick's (1974) distinction, I'll be discussing short-range, as opposed to long-range, apparent motion. Long-range apparent motion appears to depend on fronto-occipital circuits (Sanders et al., 2014), which the present model doesn't include. Critically, the basic framework developed here can be expanded to include such oscillatory circuits (see below), but for reasons of space and explanatory clarity it must be reserved for a future project.

To perceptually construct this illusory movement, the brain requires information about both flashes. But this seems to imply that brain time is sequentially ordered differently than experiential/represented time. Here's the thinking. In the brain, A and B must both be processed at some level to construct represented movement from A to B. Without processing information about B, the flash at A could not be representationally connected to B. So, in terms of brain time, A and B must both be processed before there is an experience of A moving towards B. But if the foregoing is correct, then B is processed before A is experienced, which appears at odds with R-theories. Putting this in terms of the vehicle-content debate at issue here, apparent motion arguably constitutes a case in which the order of experience (single representation of succession A -> B) fails to resemble the order of vehicular dynamics (processing of A+B leads to representation of earlier-than A leading to later-than B).

Hence, apparent motion seems to demonstrate a case in which the order of phenomenological events is asymmetrical to the order of information processing in the brain. And if that's right, then temporal representation within the specious present isn't extensionalist – because the ordinality of brain processes and experienced ordinality diverge (Dennett and Kinsbourne, 1992).

In the next chapter, I argue that that conclusion is wrong. The confusion is understandable though. We need a deeper and richer neuroscience of temporal consciousness than has thus far been discussed. By way of foreshadowing, the key mechanistic idea in my extensionalist explanation is that oscillatory dynamics at multiple time scales create multiple operational time windows that *collectively and interdependently* structure temporal representation (cf. Metzinger, 1995; Varela et al., 2001; Buzsaki, 2006; Wutz et al., 2014a; van Wassenhove, 2017).[30]

One reminder is worthwhile. Different phenomena naturally involve different time scales and temporal properties. AM is a phenomenon at the lower boundary of temporal phenomena, compared to watching a baseball in flight or listening to a fast multi-octave musical scale, e.g. This means that the conclusions drawn here can be only be provisional vis-à-vis longer temporal experiences. This is especially true if, as an increasing number of researchers suppose, there isn't a single mechanism for temporal experience but instead a host of them, varying in terms of the scale over which they

[30] Well-documented electro-dynamical measurements illustrate that the brain has no characteristic time scale for processing/activity (Buzsaki, 2006). This strongly suggests it is empirically unlikely that a single frequency of activity constitutes a sufficient vehicle for temporal representation.

preside (Nobre and Muller, 2014; Arstila and Lloyd, 2014; Montemayor, 2017; Viera, 2019). What I suppose should be said is that, given the brief time scale over which AM occurs (both objectively and subjectively), the conclusions drawn here – although possibly explanatory for more extended temporal phenomena – will be strongest in relation to the perceptually-defined specious present.[31] Since that is our target explanandum, we can begin an examination of the historical precursors to the ROM treatment of AM defended in the next chapter. Here, I'll begin with the TEM, the center of narrative gravity of the AM literature in philosophy.

3.3. The Trajectory Estimation Model (TEM)

Overall, Grush's TEM has been the key modern voice of NR-theories (Molder, 2014), and is the only fully fleshed out NR-theory of AM.[32] He has recurrently (2005/2007/2016) made the point that the temporal characteristics of various temporal illusions – such as apparent motion, the cutaneous rabbit and representational momentum – are in conflict with natural readings of R-theories, especially extensionalism, and he has put forward his TEM as a putative solution to how we can simultaneously understand the emulation-foundational nature of the brain, the temporal breadth of the specious present, and how ecologically realistic brain dynamics can help explain perceptual illusions.

[31] This is an important point, since it justifies concentrating on select theories of temporal experience constructed to explain the "lower" bounds of specious present phenomenology – i.e., phenomenology at briefer time scales – such as Grush's TEM and Arstila's TSV, among others.

[32] I will not directly address an atomic view (Lee, 2014) of apparent motion, since there is none. I will not be addressing a retentionalist view (Gallagher and Zahavi, 2014; Arstila and Lloyd, 2014) of apparent motion for the same reason, but it would presumably dovetail to some extent with some basic features of the TEM if fleshed out.

On the TEM, the trajectory estimations generated by the brain are the source of both non-punctate specious present content and ecologically useful action: "non-punctate" representational content because the trajectories produced represent temporal intervals and can only be experienced with temporal breadth; "ecologically useful action" because trajectory estimations are much more reliable indicators of processes (both internal and external) than one-off instantaneous states.[33]

The way the TEM achieves this goal is through the use of forward models that keep track of both internal and external process trajectories "for purposes of control, signal processing and estimation" (Grush, 2005; p. 215). Forward models are models of a process that are iterated to predict how the process will evolve over time. To keep the forward models as accurate as possible, the TEM utilizes both "filtering" and "smoothing" processes in its generation of predictions. Roughly speaking, filtering processes use current and past information to correct estimates, while smoothing processes make estimates about a signal or process at time *t* by including information available only after t, say *t*+1. The details of filtering and smoothing aren't critical here; what is key, however, is that both filtering and smoothing are deployed in order to help the brain generate the most accurate estimates of internal and external processes for successful organism adaptation and success.[34]

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[33] Grush's TEM depends heavily on the operation of (something like) Kalman filters (KF) to optimize signal measurement and process prediction. Roughly, Kalman filters work by generating a joint probability distribution over the variables at each time-frame based on sampling in series. This process is much more accurate than single sampling methods. As Grush explains, "qualitatively, the KF compares its expectation of what the signal should be to what it actually is, and on the basis of that mismatch adjusts its estimate of what state the real process is in" (Grush, 2004; p. 381). This KF processing is justified practically: by its effect on improving a subject's anticipatory interactions with its environment.

[34] Sometimes action is best planned largely on the basis of reaction to external signals (trusting sensory signals over internal models of such), while other times action is best planned by predominantly using internal models to predict external events (weighting internal prediction higher than sensory signal measurement) – the TEM provides a straightforward means to both ends.

Importantly for what follows, because the TEM can generate experiences based on internal models, there is no requirement that what is experienced will always reflect external reality. In this way, the TEM provides a ready theory to account for perceptual illusions, including apparent motion. Before turning to AM, let's summarize the operation of the TEM via the author's own words:

> [A key function of the TEM] is to maintain a model of the process – done by…specialized emulator circuits in the brain – in order to provide predictions about what its state will be; and to use this prediction in combination with sensor information in order to maintain a good estimate of the actual state of the system that is being interacted with… (Grush, 2004; p. 382)

Taking this concept and fully extending its significance to perception and perceptual illusions, Grush (2005) explains:

> The process model embodies expectations, presumably learned through observation, in the form of the function that describes how the process – the body and the environment – evolves over time. It is by exploiting this knowledge that such systems are able to produce estimates that are able to reduce one or another sort of expected error. Illusions are cases where the environment is comporting itself, sometimes with an experimenter's aid, in a statistically irregular way with the result that the expectation embodied in the process model leads the estimation process astray. The paradox is merely apparent. (p. 217).

Applied to AM, Grush's point might be expanded like this. There is a simple justification for the expectation embodied in the process model of the visual manifold that leads to the AM experience: presumably, the evolutionary environment did not contain many quickly successive, proximate brief flashes. But it did contain moving lights in the form of falling stars, firelight embers and various meteorological events (the tracking of which could be interrupted by attentional failures). So when the brain is trying to make sense of the flashes out of which AM is constituted, a very natural "interpretation" for the TEM to generate is a representational trajectory of a single light in motion – an interpretation with much greater ecologically validity.

On Grush's view, at every time t, the brain constructs the most plausible causal story (about the agent-environment interaction) in representational trajectories. At "every time t," adverts to every vehicular time step. Grush (2005; 2016) utilized ~20ms or so in his examples. Taking that for illustration purposes, the TEM postulates the creation (every 20ms) of a representational content trajectory of about 200ms. Why 200ms of representational content? The 200ms derives from the fact that the retrodictive integration operating during some perceptual illusions, like the flash-lag (Rao et al., 2001), is around 100ms, while the predictive estimation, operative during some perceptual illusions, like representational momentum (Grush, 2005), is also about 100ms.

Additionally, experience isn't delayed, so the order in which stimuli hit sensory receptors is the order in which the subject experiences them (especially in cases where stimuli strike receptors with a lag (~60ms for AM) that is longer than the vehicular integration interval (~20ms for TEM). So, in the AM case, according to Grush, the subject experiences A, a blank visual field, B, a blank visual field, and then the representational trajectory of A->B. Since this is not what subjects report, Grush needs a story about why subjects only report A->B.

His solution is to suppose that in the same manner that we have conscious dream experiences that are immediately forgotten, so too do we have conscious experiences at short timescales that are immediately 'overwritten', never to be recalled (cf. Dennett and Kinsbourne, 1992). Given evidence of fringe and minimally conscious states, it appears a plausible assumption (Schweitzgebel, 2008). Hence, according to the TEM, the subject does experience A, pause, B, pause, but these very brief isolated experiences are then overwritten by an experience and subsequent perception of A->B, which is remembered and reportable.[35]

Regardless, the question Grush has pressed is whether the extensionalist can also account for AM. He argues the extensionalist faces a problem of inconsistent representational contents. Simply put, the problem is that a specious present is a single experience, so can't be internally self-contradictory. However, during a specious present experience of the AM illusion, the flash of A is represented both as stationary and as part of a movement trajectory. Since extensionalists don't have access to an overwriting-type maneuver – because temporal experiences unfold like their vehicles they can't be rewritten, changed or post-dated – they are positing a framework that is internally inconsistent. With this argument, Grush claimed extensionalists can't account for AM.

[35] Is it theoretically appealing to suppose that we are often having experiences that are completely accessible at the time they are had but are in principle inaccessible even a fraction of a second afterwards? Certainly, it is correct to say we are constantly processing information and unconsciously representing events that will never come to conscious light. But if the claim is that all of these in-principle inaccessible representations fit the bill for conscious experiences, then it might be wondered what work is being played by "consciousness" here, as well as what justification there is for supposing "experience" a correct description – as opposed to say unconscious information processing. It seems more natural to say that the information contained in the purportedly "overwritten experience" was actually never consciously represented/experienced, but rather only unconsciously processed before a final conscious experience of AM occurred. Note that I am sympathetic to the idea that most of what we experience is immediately forgotten; it's specifically the inaccessibility clause that gives me pause, and makes me wonder whether "experience" is an apropos account of what's occurring.

3.4. Dainton's Delay Overlap Extensionalism (DOE)

The most worked out extensionalist view is that of Barry Dainton, who advocates (2008/2010/2014) for his "delay overlap extensionalism" (DOE) model, according to which the continuity of conscious temporal representation (i.e., the specious present) is explained by the continuity of underlying vehicles. For Dainton, what establishes strong vehicular continuity is the overlap of *numerically identical* vehicular realizers. Since vehicular realizers can be cashed out neurodynamically, we get the idea that it is the numerical identity of neurodynamical vehicles over time that generates continuous/extended representational content.

What is being bound by this overlap mechanism? What is bound are parts of a specious present: experiential phases. In the shooting star example, distinct positions of the meteor correspond to distinct experiential phases, but all the phases are united within a single specious present. Dainton's idea then is that the experiential phases in a specious present are continuous just in case the vehicular realizers between experiential phases involve the overlap of numerically identical neural ensembles (recall the overlap illustrated in figure 1). He even has a name for the special continuity that must obtain to realize experiential continuity: "phenomenal connections." Phenomenal connections are a result of the overlap of the vehicles of experiential phases and they are responsible for generating the strong continuity experienced in the specious present and in consciousness more generally.

(24) Vehicular Overlap: Temporal experience is robustly phenomenological continuous on account of experiential phases sharing numerically identical vehicles (Dainton, 2014).

Dainton claims that NR- views, which do not intone numerical identical but rather vehicular duplication, cannot generate phenomenal connections and thus fail to account for the self-evident phenomenology of temporal extension and flow. Dainton puts a lot of explanatory weight on this difference, claiming that only vehicular overlap, and not duplication, can generate phenomenological connections and hence experiential continuity. The major issue here is what to make of Dainton's concept of phenomenological connections.

It is used as an explanation-carrying term, but dissenters can reasonably wonder if the concept is explanatory. As discussed, Dainton (2014) highlights vehicular "numerical identity" of the core realizers to contrast his view from NR-views involving vehicular "duplication". His point is that only overlap of the same vehicles can explain the temporal phenomenology characteristic of the specious present – phenomenological continuity. NR-theories reject the numerical identity of vehicles between experiential phases, though they do permit duplication (though see Lee (2014) for a view that the NR-theorist can have his cake and eat it too). For the typical NR-theorist, each specious present is an atomic event. While the duplication of ongoing stimuli in successive specious presents can arguably serve to sustain the representation of given objects, for example, the processes the NR-theorist adverts to do not allow strict overlap because the vehicular events are atomic/insular.

An important question for Dainton's view is why vehicular identity would have effects at the conscious contents level not provided by vehicle duplication. There are two reasons to think Dainton is hinging his account on a difference that doesn't make a difference. One, there seem to be various cases (petit mal seizure, dreams, surgical intervention, etc.) of people going unconscious and regaining consciousness without being aware of the passage of time. This indicates that a radical change in vehicles can't simply be taken to be phenomenologically detectable. Two, on what grounds would identity as opposed to duplication exert a distinct influence on the cognitive economy? As duplicates, wouldn't they duplicate the relevant causality? Moreover, on a naturalistic picture, whatever connections exist between experiential phases would be caused by continuity in the underlying realizers, which leads us back to the question of differentiating the downstream effects of numerically identical vs. duplicate core realizers.

Dainton is vague in his characterization and explanation of phenomenal connections and this makes his overlap model a bit ungrounded. In chapter 5, I unpack the ROM model and show how it provides a naturalistic, neurobiological account of overlap that explains experiential continuity and representational discontinuity between experiential phases in terms of modulation of phase-amplitude multiplexing. So, given that my aim is not to adjudicate between the various interpretations of overlap or of phenomenal unity, but rather to provide a mechanism to account for them in the next two chapters, I turn to Dainton's defense against Grush's "inconsistent representational contents" objection. He posits that his overlap extensionalist position involves an explicit delay to conscious experience.

(25) Experiential Delay: Temporal representational content is delayed to allow for the integration of unconscious neurodynamical activity on time scales proportional in extent to the durations of temporal illusions (Dainton, 2010).

This idea that consciousness is delayed is not a new one. Eagleman and Sejnowski (2000), for example, marshal experimental findings to suggest an ~80ms delay between stimulus and conscious experience of such. Eagleman and colleagues went further in later years to hypothesize that an ~80ms integrative window was needed to harmonize signals from all over the peripheral nervous system.[36] Dainton takes this basic idea and extends it to be able to account for over 300ms+ of delay, as required by some of the temporal illusions he hopes to account for (Phillips, 2014).

Dainton's reply to Grush's inconsistent representational contents objection is simple. If the conscious experience of A is delayed until the brain can integrate it with possible subsequent information, then only one single coherent interpretation is produced. Hence, the processing occurs unconsciously in the order well described, but, given the delay, the conscious representation (hence temporal experience) amounts only to A->B. Because of the representational delay, there are no inconsistent representational contents, nor any problematic (i.e., consciousness subvening) vehicle-content asymmetries.

Axiom (25) is a disputed one. While Grush (2016) admits that a delay does sidestep his dilemma, it introduces some significant evolutionary costs. Not only would delaying conscious representation be presumably evolutionarily dangerous and therefore

[36] This idea of an integrative delay to wait for signals from the peripheral nervous system was first broadcast by Rick Grush in draft form in 2003 and introduced publicly in his (2005) talk, "Space, Time and Objects."

possibly unlikely to be naturally selected, it would threaten to make conscious representation epiphenomenal in cases where actions and decisions have to be made immediately, and therefore unconsciously. If the initiation and execution is due to unconscious processes, then the subsequent conscious representations must occur too late to do causal work. Given these problems, Grush argues, delay extensionalism is suspect and theoretically inferior to the TEM.[37]

Even extensionionalists themselves are divided on the legitimacy of (25). Ian Phillips (2014) forwards his Naïve view of temporal content, which holds that it is central to the extensionalist platform that intervals are metaphysically and epistemically prior to instants. Rashbrook-Cooper (2015m) formulates a similar argument that extensionalist experiences are individuated as "unfolding over time." Both of these arguments share the idea that the temporal content at any instant is derivative of the content of the temporal interval within which it is embedded. In other words, instantaneous temporal content is individuated by its contextualizing interval. If this is the case, Phillips (2014) argues, then there aren't conflicting stories to tell on the extensionalist view – i.e., there aren't inconsistent contents. In AM, either B happens, in which case, A->B is experienced, or B doesn't occur, in which case A is experienced as an isolated flash. Taking intervals as representationally primary, querying about the content of instants confined to instantaneous time-slices isn't an option.

[37] Grush's objections are most trenchant against DOE. An important delay theory that is not so strongly undermined is the postdiction model of David Eagleman and colleagues (2000). They posit a delay around 80 ms in conscious representation in order for signals throughout the sensory "surface" to be able to influence (through signal interpolation) the formation of a more stable (conscious) interpretation. Given that the delay attributed to DOE (Dainton, 2010; Phillips, 2014) is over three times longer than that posited by Eagleman, the strength of the delay argument is much less clear in regards to the postdiction model.

Grush (2016) lambasts this reply. Either a delay is smuggled into the final explanation, or the characterization of the interval is impotent to change the present, or the appeal to intervals courts spooky backward causation – none of these responses being convincing. Grush's main point is that there must be some fact of the matter regarding content at a given moment – a point not disputed by Phillips (2014) – and this content can't depend in any robust way on things yet to happen.

Although interesting, I am going to bracket discussion of Phillips' Naïve View because he doesn't concern himself with vehicle-content issues in any substantive way.

In addition to defending the DOE against Grush's critique against inconsistent representational contents and a costly delay, Dainton goes on the offensive against Grush's TEM. His main objection is that Grush's TEM involves a very unpalatable representational tension: vehicular events (~20ms) are an order of magnitude briefer than representational content (~200ms). One might even think that Grush (2005) himself provides some rationale for this challenge when he writes,

> When the internal process model evolves its state from one time step to the next, the function that affects this mapping should be calibrated such that it will evolve the process model's state in a way that mirrors, as closely as possible, the evolution of the state of the real process over that same amount of time. That is, if each update of the process model's state estimate takes 20ms, then the function that is used to update the state of the process model ought to change the process model's state to mirror the change the actual process undergoes in 20ms. Obviously, if every 20ms the internal model's state is updated to reflect a change that the real process would undergo in 40 or 100ms, the *a priori* estimates will not be very accurate. This time-tracking capacity…is most likely governed by some combination of the intrinsic dynamic properties of the neural structures that implement the model and timing mechanisms, such as oscillators that cycle at more or less regular intervals (p. 217-18).

On the face of it, this should strike the R-theorist as an appealing point. Since the R-theorist is committed to temporal content mirroring vehicular temporality in various ways, mirroring rules are foundational ones for her. Certainly, the easiest way for a system to ensure that a model of a process and a represented process stay synchronized is to have them operate isomorphically – by a mirroring constraint. And it is plain that the easiest ways to ensure synchronized/mirrored updating are by R-theoretical means. Moreover, Grush's reference to oscillations should be especially welcome for the ROM theorist, of course. ROM theory describes a model of the specious present in which oscillations ground a vehicle-content mirroring constraint, ensuring that represented content remains usefully accurate due to staying in step with the vehicular dynamics generating and manipulating such content. The main objection, however, is the following.

3.5. The Surplus Content Objection

Dainton's (2008) surplus content objection is based on the fact that the TEM posits that representational intervals/trajectories are created at vehicular "steps" that are much briefer than the intervals represented in temporal experience. Although Grush doesn't have an official duration for these vehicular steps, he uses ~20 ms as a guide; this is in contrast to the ~200 ms he posits are represented at every step (Grush, 2005; 2016). Dainton's objection is that for every second of objective time, there are 50 vehicular steps each producing ~200 ms of representational content. That means that in any given second, 10 seconds of subjective time would actually be experienced. This is the problem of surplus content. Dainton holds that this may be downright contradictory (phenomenologically or given experimental data), but that even if it is not, it is at least a very strong reason to be suspicious of the TEM framework.

In reply, Grush (2016) first points out that the surplus content objection can be construed as turning on a fallacy of overcounting, so to speak. A quotidian example is useful. Take a 12-inch ruler. Now measure the length of the ruler in 3-inch segments. If one allows the 3-inch segments to overlap, such that 3 inches is compounded at every inch mark, from 0-9, then one derives the result that the ruler is 30 inches. The problem here is with the counting system and not with the objective length, with the epistemology, not the metaphysics. Compare this with durations in the temporal domain. If overcounting is avoided, then the various events represented during representational intervals will also not be overcounted – nor the durations – and the objective and subjective durations will align without problem.

The surplus content objection is not so easily dispelled, however, due to the fact that the events represented by distinct vehicular steps cannot simply be taken as identical. This is because although there is representational duplication on the TEM picture; it's atomic framework mandates a lack of identity between representational contents generated by distinct vehicular steps. But without representational identity, the question of whether overcounting is an apt charge against representational duplicates seems legit. This leads Grush to the heart of his rejoinder.

Grush ingeniously argues that the appearance of contradiction highlighted in the surplus content objection depends upon a certain kind of temporal experience, involving A-ish temporal content, characterizable into past/present/future temporal coordinates.

Insofar as one experiences a "moving now" within which an accumulating past is recalled and a future anticipated, one's temporal experience involves A-ish content. Grush claims that in order to experience a temporal mismatch between objective and subjective durations, the temporal representational content would have to be A-ish. In that case, the 200 ms representational interval would seem like 200 ms and one would experience dissociation between vehicular time and experienced time. Grush's solution to the surplus content objection is that A-ish temporal content doesn't apply to the TEM. And this is because, as discussed, the TEM is an account of B-ish temporal content, of minimal temporal experience (2016).

But how does this kind of temporal content explain temporal experience? Consider temporal order blindsight, introduced above, in the case of 2 stimuli presented 25 ms apart. This is a case in which one experiences temporal asymmetry without being able to assign temporal order. To describe such an experience, A-ish content seems inapposite, since nothing is the past or future relative to the experience, which seems to happen all at once. Although the phenomenology involves one stimulus being experienced as earlier than the other, from the point of view of reflective access both flashes have indeterminate ordinality; that is, subjects cannot report which stimulus actually came first (despite the phenomenology of temporal asymmetry). In other words, the stimuli in temporal order blindsight are not past or future with regard to each other (i.e., not A-ish). Although there is an experience of non-simultaneity, the entire experience occurs within what one would typically describe as the "now" or "present moment."

The upshot is that if the surplus content objection depends upon A-ish content, then it is inapplicable to the TEM, unless all or some A-ish contents have B-ish contents as a subset. This latter possibility Grush also denies (2016). Rather, he sees B-ish contents as being typically characterized by experiences at a shorter temporal scale than A-ish contents. Now, the foregoing dialectic between Grush and Dainton represents the central thread and bulk of the vehicle-content debate on temporal experience to date.

Before turning to a critique of these accounts of AM, I will introduce the most recent addition to the conversation.

3.6. Arstila's Simple View (TSV)

Although part of his "Simple View" (2016), there is nothing simplistic about the neuroscience deployed by Arstila in his (2015) explanation of AM. The key mechanism behind his explanation of AM is the aforementioned non-linear latency difference (NLLD) thesis, which holds that temporal representation depends upon the variable latencies involved in reentrant circuitry (cf. Lamme et al., 2003; Silvanto et al., 2005). Arstila focuses on local (i.e., non-global) reentry to demonstrate that the temporal properties of vehicles and contents are not necessarily in conflict once nonlinear processing latencies are actually understood. He does this by a certain understanding of "perceptual end points," the spatiotemporal "location" at which unconscious processing becomes conscious.

The fundamental idea of NLLD is that once you individuate perceptual end points by the completion of reentrant circuits, then activating such circuits by alternative neural routes generates a representational 'fast-track' for motion, such that the motion experienced from A->B occurs earlier than the experience of the detailed location of B. This 'fast-tracking' of stimuli allows for non-linear processing dynamics that explain how vehicle-content isomorphism isn't ruled out during AM and similar illusions. Having an idea of where we're headed, let me turn to an accessible introduction to TSV's account of AM, provided by Arstila (2015):[38]

> The presentation of the second stimulus in apparent motion experiments causes activation in two separate streams of processing. One concerns (apparent) motion and the other concerns the stationary stimulus and its color, shape and other fine details. Processing related to motion proceeds faster than in the other stream, and therefore motion processing finishes first. As a result, the experience of motion begins before we experience the second stimulus. At this point the moving thing has the properties of the first stimulus. If the used stimuli differ in regard to their color or shape, these properties are experienced to change suddenly or gradually to the properties of the second stimulus. Because the properties of a moving object are updated faster than a new object representation (i.e. the representation of the second stimulus) is constructed, the moving object changes its properties before we perceive anything in the location of the second stimulus (p. 17).

In a little more detail, AM begins with a stimulus A that is processed only via a slow parvocellular signal that initializes a reentrant circuit in the normal way to represent a flash.[39] As that reentrant circuit is becoming active, stimulus B triggers activity in both parvocellular and magnocellular pathways. This magnocellular signal reaches V5 before V1 can generate a reentrant circuit, and hence motion processing begins before object

[38] As will be obvious in the next chapter, this paper was a major inspiration for the ROM model of AM.
[39] One critical implementation-level distinction between TSV and ROM-theory is that ROM-theory takes retinal signals to activate both parvocellular and magnocellular signal channels, though to a context-dependent extent (see above) – i.e., as the spatiotemporal distance between attended stimuli increases, magnocellular signal strength is proportionally diminished. This is an advantage here, since, while ROM-theory can coherently explain all the information processing in AM, Arstila appears to have no comfortable answer as to why the stationary stimulus B, but not the stationary stimulus A, activates magnocellular pathways. Unless stationary signals activate magnocellular pathways at least minimally, as ROM-theory maintains, it is totally unclear how and why the AM stimuli would actually stimulate the brain in the manner Arstila claims.

representation of B. Because TSV holds that reentrant circuits are instantaneous perceptual end points, once V5 feedback about B reaches V1, it is conjoined with the forming representation of A to represent A at L1 in motion towards L2. This fast-tracking of information about B's location to influence the processing of A is an example of the role of non-linearity in the NLLD. As the parvocellular signal about B is finally integrated into the circuit, the information about A has already elapsed, leaving the impression of a single stationary end point of the trajectory A->B.

3.7. Foreshadowing: Relation of ROM theory to Other Accounts

(i) Like the TEM, ROM theory does not posit a delay in representation. Representational processes have circuit-dependent latencies, but there is no additional delay.

(ii) Like the DOE, ROM theory posits that R-theory temporal representation involves the overlap of numerically identical vehicular realizers. In ROM, these realizers are hierarchically nested oscillations.

(iii) Like the TSV, ROM theory posits that the latencies of reentrant circuits are central to explaining R-theory temporal representation.

Hence, the plausibility of ROM will suggest the plausibility of various aspects of its competitors. I turn to a discussion of these rival views of AM.

3.8. Discussion of AM models

3.8.1. Introduction

In what follows, I will offer some critiques of the just-canvased positions, but recall my humble goal: to show the higher plausibility of the ROM view by casting reasonable doubt on the sufficiency of other views and by demonstrating the fecundity of the ROM view. So I don't take my critiques to be exhaustive or to require as much. I will spend more time discussing the TEM because I think it deserves more discussion, on the one hand, and that my objections to the other accounts vis-à-vis ROM are much more damaging.

Foreshadowing, I claim that the DOE is problematic in the length of its delay, its lack of neurobiological detail, and potential conflict with empirical data. I claim that the TSV model is possibly incoherent in its claim to be cinematic yet generate direct movement experiences phenomenology," and in its amalgam of theoretical elements. Lastly, I claim that the TEM offers a limited account of thick phenomenology of the specious present as normally conceived, that overwriting and computational costs are possibly problematic, and that it may be in tension with some empirical evidence about neurodynamics.

3.8.2. Critique of DOE

The first general concern is that a delay of conscious representation – although it solves the inconsistency objection – has two problems that may be even worse. One, a delay of conscious representation is evolutionary costly. Two, a serious delay of conscious representation may imply a troublesome degree of conscious epiphenomenalism. In part due to the force of these objections, Ian Phillips plumps for a distinct version and defense of extensionalism.[40] But what of DOE?

I argue that while the relation of delay and conscious representation is unclear, we can assume that distinct environmental contexts might select for radically distinct responses, some of which would involve immediate responses too quick for conscious deliberation. So some unconscious action initiation is unproblematic from my perspective; in fact, it seems evolutionary justified.

What is difficult to adjudicate is whether a policy allowing extra delays of 1/3rd second+ is evolutionary justified. Certainly, many contexts would prove such delays to be not only unnecessary but also counterproductive. Interestingly, as mentioned, other extensionalists have expressed skepticism. As mentioned above, even Phillips (2014) and Rashbrook-Cooper (2015/2016), influenced by Dainton, are both uncomfortable with such a delay.

A further weakness of DOE is its lack of vehicular details. Dainton (2014) discusses “overlapping realizers” that share “numerically identical” parts, but he doesn’t

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[40] As explained above, Phillips’ Naïve View is a content-content extensionalist approach and so orthogonal to the discussion here. What is notable, however, is his dissatisfaction with the length of delay required by the DOE.

go beyond this; hence, there is insufficient engagement with the neuroscience of temporal experience.

Arstila (2015; p. 12-14), as well, has articulated fresh objections against delay models like DOE. On DOE's explanation of AM, the conscious experience of motion is a delayed product of inference generated from pre-experiential states. On DOE, the interpretation of motion is produced by (hence post-dates) the unconscious registration of static stimuli. Arstila points out that the empirical results do not support this. Specifically, neuroscience shows that motion isn't a result of a delayed interpretation; rather, the early activation of V5 via the magnocellular pathway explaining the activation of motion processing in blindsight patients shows that the system interprets stimuli as motion from the outset.

Finally, as we will see, the existence of ROM, which embraces an overlap and hierarchical oscillatory structure within a mechanistic account supported by current science, arguably makes the DOE otiose. Where the DOE adverts to circular explanations rooted in "phenomenal connections," ROM puts neural mechanisms on the table to explain how specious presents can contain the experiences of both simultaneity and succession; of how specious presents overlap mechanistically, and so forth (ch. 5). Given the existence of a mechanistic account of the specious present that provides an overlap extensionalism without delays, vague terms-of-art or empirical tensions, the DOE has questionable utility for extensionalists. I turn to Arstila's TSV.

3.8.3. Critique of TSV

Arstila (2016) claims the TSV is the simplest possible theory of temporal experience because it is a cinematic resemblance theory. So it has the one-dimensionality of R-theories plus the one-dimensionality of cinematic theories. Whether this is a merit is another question; it might be cutting too much meat off the bone to provide a sufficient explanatory meal, as we'll see.

The big problem for any view like TSV is to account for our self-evident experiences of motion, succession and change (natural on a specious present account) with a view committed to instantaneous contents. Since it rejects the reality of the specious present, TSV can't account for the experience of motion through the direct representation of object motion – i.e., explicit spatial displacement within a representational interval. To attempt to account for motion in an alternate form, Arstila argues for "pure phenomenology."

The paradigm instance of pure phenomenology is pure motion, which is the experience of motion without the explicit representation of object movement. Putative examples are the waterfall and rotating snakes illusions, in which subjects experience movement while also failing to find explicit objects moving. Arstila's idea is that if pure motion is possible, then it is theoretically possible to account for the experience of motion in AM with a view that officially rejects the specious present. Hence, he takes TSV, buoyed by the dynamic snapshot view (25), to account for AM while respecting instantaneous contents (20).

Arstila's characterization and deployment of pure motion can be questioned. As Grush (per. comm.) puts it, "this all seems very suspicious to me. The subjects can very well tell you what it is that appears to be moving. It's the objects that compose the 'snakes' or circles or whatever."

But there is a serious objection even if we grant Arstila the coherence of pure phenomenology: although important and clever, doesn't sidestep the issue of how those processes are themselves best characterized. Most pointedly, TSV accounts for the direct experience of motion/temporal breadth through axiom (24), but, critically, we are given *no reason for thinking that the mechanism that generates pure phenomenology isn't itself an extensionalist process*. In fact, Arstila's (2015) description of the multi-level encapsulated processes generating pure phenomenology sound a lot like the extensionalist mechanisms of ROM theory we'll see in ch. 5, making the assumption of instantaneity quite problematic. This is a huge concession because it leaves open the possibility that the local mechanisms appealed to by Arstila actually operate according to extensionalist dynamics!

Returning to Grush's concerns, he asks whether any theory that accounts for a direct experience of motion, by whatever means, isn't a *de facto* specious present view. This is an interesting point, since it potentially flips the discussion. If Grush is right, then the TSV is either internally inconsistent or reestablishes consistency by rejecting (20) and embracing (2), the specious present doctrine. The basic issue is whether a theory can postulate an experience of motion in a minimal temporal experience and be anything other than a version of a specious present theory. Arstila claims that the experience or phenomenology of motion can be divorced from the representation of motion detail. So, is Grush or Arstila right?

I think Grush is correct here. Cinematic views (like TSV) are defined in terms of instantaneous contents. But motion content, by definition, is something that cannot occur as an instantaneous content. If TSV wants to account for motion via a special axiom of the dynamic snapshot view, that is all and well, but it changes the nature of the theory, since motion is included in the fundamental phenomenology.

A further serious objection that overlaps in implication with the foregoing is that the instantaneous axiom (20) of TSV in combination with a commitment to an R-theory is unsound, given what we know about neurodynamics. Recall that for R-theories, there is an explanatory resemblance between vehicle and content: so instantaneous content is produced by an instantaneous vehicle: Arstila's "end point." But there is nothing about psychological processes or the neuroscience of the brain more generally that is properly characterized by instantaneity on a scale large enough to have neurofunctional relevance – and this applies both to neurodynamical vehicles and to represented experiential content (phenomenology). Rather, all aspects of the brain and the mind seem better described by neurodynamical *and* representational trajectories, however brief (Varela et al., 1991; Grush, 2005; Buzsaki, 2006; Spivey, 2007). This includes spike rates defined over intervals, all population codes, the time course of ramping neurons, spike-dependent synaptic plasticity mechanisms, oscillatory dynamics…an indefinite list could be adduced. What they all share in common is that functional brain processes occur in time, take time to shape information flows in the brain, and operate over time.[41]

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[41] An accompanying objection to TSV involves the fact that explaining dynamic continuity in terms of the succession of instantaneous contents arguably falls flat. James (1890) pointed out, "a succession

I suggest, then, that TSV is implausible on a host of grounds.

3.8.4. Critique of the TEM

The TEM is the seminal algorithmic theory in the philosophy of temporal perception, and has inspired recent computational efforts (Wiese, 2017). Grush's work (2004; 2005) is also notable in being one of the first to highlight the importance of emulation for theories of cognition and consciousness; arguably the developments into predictive and generative[42] models follow his early work.[43] The TEM is organized around a few key ideas, canvased in the last chapter. Here, I want to focus on the central concept of emulation. Emulation involves prediction, and since I believe the brain is aptly described as a predictive engine, I am entirely supportive of the basic motivation behind the TEM. The emulative idea, moreover, is manifested in a statistical framework that gives an idea of how the brain might function in terms of abstract processing steps. All of this is important work and work with which I generally agree.

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of feelings, in itself, is not a feeling of succession" (p. 627). If phenomenological continuity is explained by the continuity of representational contents, and those contents require temporally-conserved neural activation patterns (i.e., the activity of representational vehicles involves neural inertia in beginning and ending neural activation) – as neuroscience seems to require! (Buzsaki, 2006) – then even TSV requires a neural story incorporating basic continuity of neurodynamics to generate phenomenological continuity, which begins to look more like an extensionalist view! I leave this as a footnote, since Arstila it either begs the question against his view or fails to understand his use of "perceptual end points."

[42] Generative models are unified by the idea that the brain is a predictive engine and that "higher" cortical areas send feedback signals to anticipate the activity of "lower" primary cortical areas, which in turn send feedforward error signals to continually correct the higher-order predictions in pursuit of multi-dimensional signal congruence. Empirical studies support, in many ways, the further idea that conscious perception corresponds to violations of expectation/prediction. The idea of a hierarchically integrated predictive oscillatory framework is perfectly congruent with ROM. It is also an algorithmic feature of the TEM, whose estimations *just are* predictive trajectories. Some advocates of generative models have argued that the TEM, however, cannot account for critical features of immanent temporal experience (Hohwy, 2016; Weise, 2017), a point I will reinforce below.

[43] ROM theory makes the prediction that the first forward models were neural oscillations entraining to survival-enhancing environmental regularities.

I have various questions about the sufficiency of the TEM, but I want to focus on five central ones. Concern (1) comes from Arstila (2015/2016). He complains that even bracketing the fact that the TEM, like all time marker views, is insufficiently developed to be truly useful, it is also in conflict with empirical data, which can't simply be flagged. The conflict is between the duration afforded for the AM experience, on the one hand, and the amount of time over which AM experiences actually develop, on the other. Specifically, on the TEM, the AM experience is generated in a momentary episode of overwriting; the vehicular event is very brief. However, neurophysiological evidence shows that AM experiences require lengthy vehicular processes.[44] Arstila (2015; p. 10) mentions both the feedback loop from V5 to V1, and motion masking studies to reinforce his point. The ROM model, as well, provides a plausible explanation for AM in the context of neurodynamical circuits extending over 200+ms. One might think that Grush could sidestep this problem by simply lengthening his postulate for vehicular processing. But Arstila (2015) argues that lengthening the vehicular duration (in line with empirical results) would not be in Grush's interest, as it would undermine Grush's point about the advantage of conscious immediacy the TEM has over rival delay models, like DOE and Eagleman's postdiction account.

In response, Grush says,

> Maybe. But my view isn't that everything required to do the processing is a part of the relevant vehicle. Maybe there are processes that take 500ms that result in

[44] Arstila's objection may backfire on him. Once committed to lengthy vehicular processes and instantaneous contents, it looks like he begins to advocate for a stroboscopic model of consciousness. This isn't necessarily a problem, but it will be objectionable to many theorists. More of an issue may be that positing lengthy vehicular dynamics as generators of pure phenomenology may entail internal or empirical inconsistencies. Since there are larger issues with Arstila's TSV (discussed above), I'll leave these as skeletal worries.

> another different neural state that is much shorter, and the second is the vehicle of the experience. The exact stamping of a date on a letter is instantaneous, but the mechanisms that decide what date to stamp might take a while (per. comm.).

I think it's important to note this reply for completeness, and it's clear how Grush intends to sidestep Arstila's criticism thereby. But without an account of how to individuate vehicular realizers, this defense seems either ad hoc or at least incomplete. ROM is an attempt to identify the relevant realizers, and it holds that lengthy processes (in ms) realize conscious states. But without something along those lines, it's hard to rest too much weight on Grush's rejoinder. I'll return to this in making my final point.

Regardless, perhaps Grush can employ his overwriting story to patch up this objection, but that patching might begin to look a little ad hoc. Specifically, Grush can claim that 20ms vehicular events do generate all kinds of representational contents – even inaccurate, contradictory and sequentially incoherent contents – but that these are overwritten vis-à-vis reportable consciousness. To my mind, that should silence Arstila's objection. But it seems to invite a larger one: if any discrepancy between plausible neurodynamical processing time and the temporal trajectory of conscious representation can be accommodated by an overwriting panacea, then an "embarrassment of riches" objection appears. Specifically, Grush can maintain that 20ms vehicular events continually generate 200ms of representational content and that the vast amounts of representational contents that are poor models of the environment (due to failing to incorporate critical information presented immediately after the 20ms vehicular event) are overwritten – an interpretation very much in the spirit of the seminal NR multiple drafts model of Dennett and Kinsbourne (1992). However, one might hope for a theory that has empirical consequences that can't be sidestepped by a universal theoretical salve.

I think all naturalists at least, Grush included, can agree a more palatable solution would draw a tighter connection between representational contents and their vehicles. I'll return to this in my final point. I respect the motivation behind NR views like the TEM, but the overwriting axiom, which would be in continuous operation, almost seems too good (or too magical) to be true – or so it seems to me.

Concern (2) is over the computational cost of the TEM, which has both postdictive and predictive functions computing multiple trajectories for multiple objects at all time points.[45] At *every* vehicular onset – every 20 ms, e.g. – the cognitive economy has to begin computation of trajectories for earlier, present and later time points.[46] Computational processes occur unabated during conscious experience. Moreover, there are additional higher-order computational constraints on ongoing computations: at each time step, a decision has to made regarding the processing depth – trajectory length – for a given stimulus estimation. Potentially altering default trajectory interval lengths – i.e., how extended a given trajectory estimation at a given time point should be – is needed to compensate for salient changes in the environment.

These computational burdens seem unrealistically severe. Take a subject perceiving fireworks, running through a jungle, or navigating a complicated first-person shooter video game – or even more complex scenarios like real warfare. Such situations present subjects with a vast manifold of objects moving in distinct and competing trajectories, most of which are highly salient. The facility with which subjects routinely

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[45] Note that Grush (2016) argues that other models that posit a delay require the same machinery and are thus as computationally expensive. If he is right, my objection applies to all such approaches.

[46] At each vehicular time step, the TEM generates a trajectory estimate that is both retrospective and prospective. That is why the TEM is a theory of the specious present: it is inherently intervallic. The depth of the trajectory estimate can be characterized in terms of time steps; e.g., what happens at t-1, t-2, t-3, etc., or what happens at t+1, t+2, etc. Notice that both the retrospective and prospective trajectory depths for every estimate are further computational variables.

handle such contexts, preserving energy and focus for further activities, seem to bely the enormous cognitive feat described by TEM dynamics. However, this could turn out to boil down to a difference of intuitions, so I won't place much weight on it, but another reflection in this vein is worth mentioning.

Certainly, an indefinite number of objects being tracked at an indefinite number of degrees of depth is computationally implausible. In his defense, Grush might intone the workings of attentional processes to narrow down the number of trajectories requiring calculation and trajectory depth recalibrations. Now, there are multiple well-recognized loci of attentional processing; various regions of the frontal cortex, the anterior cingulate cortex and the parietal cortex (inferior parietal lobule, e.g.) all have abundant experimental evidence correlating their operation with attentional functions. But there is a problem: the signaling and processing duration from these attentional centers to the visual circuits computing basic AM information is well beyond the posited 20ms vehicular atom. So neurophysiology/neurodynamics suggests that attentional processes can't affect vehicular processing in, at least, a timely manner. Rather, attentional processes would always be lagging, which seems right. For the sake of argument, say that attentional processes, by continuously operating, have a lagging but concrete effect on limiting the computational burden of the TEM algorithm to the point of neurodynamical plausibility. At this point of neuroscientific understanding, Grush's model should be granted that. However, as I see it, there is still a lingering issue. Invoking a lagging attentional process further sharpens the just-noted conflict concerning the frequent need for overwriting. My reasoning is that the lag in attentional processes implies a failure to prevent a nontrivial amount of inaccurate or ecologically-irrelevant computation. Hence, the process of overwriting will itself be a significant computational burden. So it seems that leveraging attentional processes to reduce computational burdens isn't convincing; not only does the computational burden objection still stand, due to the ubiquitous need for overwriting, it also appears to compound the previous overwriting objection.

Concern (3) with the TEM is Grush's counter to Dainton's surplus content objection. And I want to be honest at the outset that Grush's response is a bit mysterious to me. With that in mind, my confusion involves the following reflections.

While I follow Grush on his invention that the specious present should be characterized by "Bish" temporal contents, I think that the specious present is wide enough to contain degrees of non-simultaneity. That is, introspectively, within the same specious present, there seems to be degrees of earlier-than/later-than. Within a unified conscious moment of seeing a shooting star or hearing a brief chord progression, I experience an extended progression that involves multiple representations of earlier-than. And this is embedded in the trajectory estimations of the TEM: trajectories are defined in terms of t-1, t-2, t-3, etc. While I do not have a problem assuming that the temporal metrics of the successive steps within such brief experiences are introspectively opaque, I do believe they can contribute to basic temporal phenomenology, and admitting this may change the way we think about Grush's rejoinder. Recall that his defense to the surplus content objection turned on the claim that only 200ms of A-ish (and not B-ish) representational content *seems* like 200ms. However, once we admit felt degrees of temporal succession constitute part of B-ish content, it isn't clear to me that 200ms of B-ish content wouldn't feel like 200ms. In fact, it seems to me that it would.

In correspondence, Grush has replied to this concern (3) with a recent sharpening of his position:

> I don't want to say that 200ms doesn't seem like 200ms. What I want to say is this. Consider 2 successive 200ms estimates that overlap by 180ms. The first is t0-t200, the second t20-t220, and they overlap about 20-200. What I want to say is that the overlapping 180ms only seems like a DIFFERENT 180ms in the two estimates if the contents are A-ish. If they are B-ish, they seem like the SAME 180ms. Even though the experiences are generated at different times, they aren't experienced as concerning different times. (per. comm., 2020)

I think this is a very interesting clarification, but this strikes me as an assertion wanting defense. It isn't clear to me that the assertion is true, but even if it is, I need a little more help to understand why it is true. Moreover, I want to ask whether cases of overwriting wouldn't be cases in which consecutive B-ish estimates would feel different, due to the lack of overlap. Again, it seems to me that it would, but I admit I don't have a lot of intuitions on this or how to determine the answer.

Concern (4) amounts to sharing the analyses of a couple predictive processing theorists, both of whom take the TEM very seriously and are generally sympathetic to it, but claim it has some limitations accounting for the phenomenology of the specious present. There is a natural consonance between the TEM and predictive processing because the TEM *just is* a theory of predictive processing in which perception corresponds not to external reality, but to internally generated predictions. Of course, these predictions are constantly compared to external stimuli so as to make the estimates accurate guides for perception and action, so they are generally reliable, but like predictive processing models generally, perceptual content and external references can come apart in certain cases.

The inferential nature of the TEM algorithm grounds its connection with predictive processing. So what is the problem? Wanja Wiese (2017) argues that the TEM cannot account for the temporal extension or continuity of, and between, specious presents. In order to accommodate these features, he offers a modification of the TEM into a hierarchically distributed "HiTEM." The hierarchical interdependencies characteristic of the HiTEM, he claims, can account for the phenomenology of temporal extension and continuity – critical explananda for explaining the specious present. The details of Wiese's (2017) paper would take us too far afield, but they can be summarized. Wiese essentially claims that the atomic nature of the TEM's vehicular structure prevents it from being capable of handling non-atomic features of immanent temporal experience (like extension and continuity).

Similarly, Hohwy (2016) claims that although the TEM can explain changing intervallic temporal content, he is dubious it can account for "the sense of temporal flow" (p. 330). He motivates this claim by considering two cases in which radical discontinuities between environmental causes and phenomenology – bistable perception and movement initiation – show that the sense of time flowing isn't tied to the sensory tracking mechanism of the TEM.

Grush has a ready reply to both objections. Since the TEM is only a theory for the "now" part of temporal experience, it is a mistake to expect it to account for phenomenological features between "now"s, such as extension, continuity or sense of temporal flow. Arguably, these are all features constituted by either multiple specious presents or the relation between them. It is no objection to the TEM that it doesn't explain experiential properties it isn't designed to accommodate.

If that's false, then the TEM is on the hook for some version of these desiderata, but if that's correct, then if any such experiential properties – temporal extension, temporal continuity and sense of temporal flow – are intrinsic features of the specious present ideally construed[47], then the TEM is likely to be of only restricted theoretical value. But I am sure Grush has no beef with this. He will be happy if the TEM does the restricted job it was designed to do: describe conscious experience over a range of 200-300ms.

The main point is this. A full, complete theory of the specious present should contain enough representational breadth to explain a wider gamut of sub-second phenomena. By my lights, a robust theory of the specious present should have at least ~750ms of the representational breadth.[48] But if that's the case, then we need a story of how the TEM atoms aggregate and the phenomenological sequelae. This relates to the foregoing concerns about how the TEM will explicate the "sense of flow", for example. Thus, there is very strong reason to think the TEM, or any theory of minimal specious present content, can only be part of the full story philosophers seek regarding the specious present. Again, I am pretty sure Grush is happy with that, as long as the cog he's bringing to the clock plays its required role well. But to my mind, it shows the importance of ROM theory, to be unpacked in detail in chapter 5, due to its incredible utility.

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[47] Admittedly, how the specious present is to be ideally construed is a vexed question for sure, since characterization of the specious present will likely be task- and experiment-dependent. However, maybe there is a family resemblance concept based on basic desiderata presented introspectively (continuity, flow, brief unity of experiential phases, etc.).

[48] Foreshadowing, on ROM, this ~750ms may be realized by delta oscillations. They typically range from 1-4Hz, corresponding to specious presents comprised of 250-1000ms of representational content, which, I will argue, seems more apt for a general theory of the specious present. This representational duration also seems more apt for the unity of perception-action cycles.

This brings me to concern (5). Grush has long postulated 20ms as the length of vehicular dynamics. I know he's not wedded to that exact number, but something around there, and probably definitely less than 50ms (and maybe that's too high for his tastes). When we look at the TEM, we notice that a lot of information is supposed to be being integrated all the time. Given the TEM's formalization of generative self-correcting forward models for use in action guidance, a realistic implementation model of the *minimal* brain activity involved in a visually-guided movement includes signals from the (i) motor cortex and (ii) visual cortex being integrated by processing in the (iii) parietal association cortex. And these aren't one-way signals. The comparisons implied in the filtering, predicting and especially smoothing functions require for their implementation feedforward and feedback signals plus time for their integration, comparison, and the generation of a new signal, which must be sent to the motor cortex for relay to the musculature.

The 20ms vehicular event postulated by Grush could be argued to include all the time involved in signaling and integration and so forth that constitutes the vehicle as such. Assuming that integration events require about the total of feedforward plus feedback times, 200Hz feedforward and feedback signals would permit 10ms of integration time. Now there are 200Hz oscillations in the brain, called "ripples," but they are usually associated with unconscious states! Regardless, 10ms isn't remotely enough time to properly integrate the signals coming into the parietal from the visual and motor cortices. And it certainly isn't long enough to encompass the feedforward+feedback circuits required to implement the TEM algorithm's forward model components. The experimentally-supported numbers provided in the next chapter will give an idea of realistic estimates. There, we will see, that a very minimal estimate for the time required to generate the apparent motion experience, factoring in retina-LGN-V1-V5, involves *at least* 175-235ms of circuit activity, and the circuits being implicated on the TEM action-affordance picture require even longer latencies. The upshot is that the empirical facts of implementation for signal integration across multiple, distributed brain areas require much, much longer vehicular processes than Grush allows.

Grush has already voiced his reply: that the lengthy processes I've just alluded to are part of what's required to generate the relevant content, but are not part of the vehicle. As discussed above, this seems rather ad hoc. On what basis could one say the very signals comprising the model's key filtering, predicting and smoothing functions aren't part of the vehicle that determines the content? On what grounds would some, but not other, parts of the instantiation of the model's algorithm be considered vehicle? These are key, but unresolved, questions, so I don't think this reply from Grush is convincing as is.

None of these objections is a refutation, clear or otherwise, of the TEM. I am content, however, if these reflections place the burden of argument on defenders of that view, and the balance of plausibility on the ROM model.

3.9. Conclusion

In this chapter, I have examined various explanations of AM, the central experimental case study cited in the philosophical debate on immanent temporal experience. I began by introducing the major player in temporal perception, the

Trajectory Estimation Model, which accounts for AM by a combination of trajectory estimation (serving ecological plausibility) and overwriting. The TEM was forwarded in contrast to extensionalist theories that Grush argued could not account for temporal illusions. Dainton's Delay Overlap Extensionalism attempts to explain AM by positing a delay in the representational machinery, such that only one representation of the stimuli prompting the AM experience is ever generated. In addition to offering this account, Dainton forwarded the Surplus Content Objection against the TEM, claiming the TEM would generate too much representational content to square with introspection. Finally, Arstila's Simple View presents a differential latency theory to explain AM experiences. Briefly put, he argues that it takes longer to process the parvocellular information about the AM stimuli than the magnocellular information. I then discussed some weaknesses with each of the foregoing.

My basic arguments were the following. DOE requires an implausible delay, is bereft of neurophysiological details, and may be in conflict with empirical results. TSV imports a possibly incoherent model of temporal content and may rest on a false alternative to the specious present (which it nominally rejects). Finally, the critical NR-theory, the TEM, has some potentially troublesome aspects, such as concerns about overwriting, computational excess, the precise nature of B-ish content and possible phenomenological insufficiency in explaining the "thicker" – i.e., phenomenologically richer – properties of the specious present.

In contrast, as I will show in the next chapter, the ROM model does not posit a delay; it is neurophysiologically robust; it eschews any notion of instantaneity (on both vehicular and content levels); it doesn't involve overwriting; it isn't computationally excessive – in fact the energy in oscillations during constructive interference generates free energy – and it provides a mechanism (partial phase resetting) for accounting for phenomena both within and between specious presents, making it a plausible, predictively fecund theory of immanent temporal consciousness.

Chapter 4: The ROM Account of Apparent Motion

4.1. Introduction

The purpose of this chapter is to provide a proof of principle that temporal illusions do not, by themselves, invalidate extensionalist theories. I utilize experimentally derived information about brain time (latencies and circuit oscillation speeds) to show that when a detailed idea about how the visual cortex generates the apparent motion (AM) phenomenon is laid out, the experiential time resembles and is explained by the facts about brain time. I argue that this model shows the argument for extensionalism of the specious present is based on robust empirical results. By way of foreshadowing, the key mechanistic idea in my extensionalist explanation is that oscillatory dynamics at multiple time scales create multiple operational time windows that *collectively and interdependently* structure temporal representation (cf. Metzinger, 1995; Varela et al., 2001; Buzsaki, 2006; Wutz et al., 2014a; van Wassenhove, 2017).[49] That is, the specious present is realized by reentrant oscillatory multiplexing, and when the oscillatory rates in the visual cortex are taken into account alongside reentrant circuit latencies, an extensionalist explanation of apparent motion falls out of the experimental data. More specifically, the fast tracking of motion signals in the cortex explains why motion representation precedes the representation of the detailed location of the endpoint of the AM phenomenon. And this last point explains why the presented model is

[49] Well-documented electro-dynamical measurements illustrate that the brain has no characteristic time scale for processing/activity (Buzsaki, 2006). This strongly suggests it is empirically unlikely that a single frequency of activity constitutes a sufficient vehicle for temporal representation.

extensionalist: temporal representational content unfolds in the order of its vehicular realizers over time, in contrast to NR-theories, according to which temporal representational content is produced full-blown all at once, during a single processing step.

4.2. The Neuroscience of Apparent Motion

In this section, I provide an experimentally supported chronology of the striate and extrastriate neurodynamics that plausibly realize the short-range AM illusion. The details are somewhat involved, but the payoff is large: one can see that experienced contents evolve in the same order over time as the brain dynamics that produce them, as extensionalists claim (Stern, 1897; Dainton, 2010; Phillips, 2014; Rashbrook-Cooper, 2016).

There are some important early precursors to the neurodynamical approach I will develop here, and I am indebted to Haluk Ogmen for bringing them to my attention. Grossberg and Rudd (1989) present a mechanistic oriented-filter AM model that utilizes the multiplexing of various stimulus properties into a complex, unified visual representation. Given the focus on multiplexing, this directly foreshadows the neuro-architectural model developed here. And Ogmen (1993) develops a detailed feedback-driven model of the visual system that operates continuously via overlapping circuit dynamics. As he describes his model:

> In a continuous-time setting, [the model's] phases unfold in an overlapping manner. The network does not discretely jump from one phase to another. Its activity is continuously modulated by feedforward inhibitory, excitatory, and

> feedback influences and the resulting pattern is a sharpened continuously moving boundary signal across the retinotopic cortical surface. The critical factor is the dominance of tendencies at different retinotopic positions in continuous-time (Ogmen, 1993; p. 258).

This directly suggests the extensionalism and implies the multiplexing advocated herein. In addition to the goals mentioned above, one key extension provided by the present work is as a unifying account of immanent conscious representation. While there is only space to make a case in the visuo-temporal domain, the approach I outline has deeper aspirations supported by an increasing body of neuroscientific data (Voytek and Knight, 2015).

Before proceeding to my differential latency model of apparent motion, a few critical caveats have to be made. A complete treatment of apparent motion phenomena would include a much broader network than I have space to present. First of all, as Edelman and Tononi (2000), Buzsaki (2006) and Ronconi and Melcher (2017) discuss, thalamocortical signals are a continuous influence on cortical dynamics. Therefore, modulatory cortical signals sent back to the thalamus, the effects of those signals on thalamic gating of further retinal signals, and the effect of the LGN modulation for further signaling to the visual cortex are part of the full story. Battelli et al. (2007) and VanRullen et al. (2008) also show that TMS to the inferior parietal lobule (IPL) can impair the perception of apparent motion, so the influence of signals to and from the IPL plays a part in a complete picture. Sanders et al. (2014) present evidence that fronto-occipital oscillatory coherence increases perception of apparent motion at low but not high presentation frequencies, suggesting Braddick's distinction between short and long-range apparent motion is rooted in whether apparent motion involves top-down attention or not (cf. Verstraten et al. (2000)). Finally, Jantzen et al. (2013) demonstrate that oscillatory coherences between the primary motor cortex and the dorsal stream (parietal and dorsal visual cortices) enhance the apparent motion illusion when motor actions are directionally congruent with apparent motion stimuli. Hence, various instances of apparent motion can result from myriad neurodynamical circuit combinations.

It would seem shortsighted, however, to underestimate the value of looking at purely visual circuits in order to understand the simplest kinds of apparent motion illusion. While damage to frontal, primary motor and parietal structures all correspond to experimentally demonstrated deficits in apparent motion perception, they do not entirely ablate it (cf. Battelli et al., 2007; VanRullen et al., 2008). There appears, therefore, to be a simple kind of apparent motion that can survive attentional impairments (unless the attentional impairment is so severe as to generate complete neglect, but that case isn't specific to apparent motion but to vision simpliciter). As a result of this reasoning, and in the interests of presenting the most straightforward demonstration – proof of principle – possible, I proceed to give an account of basic apparent motion arising from visual circuit activation. That apparent motion illusions can and do result from more complex network dynamics is tangential to the chief point I wish to make: that simple apparent motion perception can be explained in a manner supportive of the extensionalist and differential latency views.

To follow the explanation, it is essential to understand some features of neural timing. There are two kinds of timing that are important: (i) signal latencies between key brain areas and (ii) processing integration windows within those areas. Key brain areas necessary for producing the experience of apparent motion include V1, the primary visual cortex, V5, the cortex responsible for realizing the phenomenology of visual motion, and the lateral geniculate nucleus of the thalamus (LGN), which is necessary for visual consciousness simpliciter. Research has shown the importance of feedback signals from V5 to V1 to generate motion percepts (Muckli et al., 2005; Silvanto et al., 2005; Laycock et al., 2007). To keep things manageable, I will focus my discussion on signals from the retina to V1 and V5 (mediated by distinct parvocellular and magnocellular circuits, responsible for stable visual details and changing visual transients, respectively) and the ensuing feedforward and feedback information processing between V1 and V5.

Regarding (i), experimental evidence on primates suggests that signal latencies from the retina and V1 fall somewhere between 20-60ms, while latencies from the retina to V5 have a lower bound of ~25-30ms (cf. Beckers and Zeki, 1995; Chen et al., 2007). Roughly following Beckers and Zeki (1995), I will use 30ms to characterize the latency of retina-V5 magnocellular signals, and 40ms to characterize the latency of parvocellular rentina-V1 signals for humans. Although these are most likely shorter than average human latencies, there is no reason to think the proportion (which is what is critical here) isn't roughly accurate. For signaling times between V1 and V5, there is evidence that latencies are between 10-50 ms (Beckers and Zeki, 1995; Pasual-Leone and Walsh, 2001; Wibral et al., 2009) and that feedforward and feedback signal latencies are roughly equal (Raguiel et al., 1999; Bullier, 2001). To simplify discussion, I will thus take 25ms as the signal latency for both feedforward and feedback activities between V1 and V5.[50] (See fig. 6 (b)).

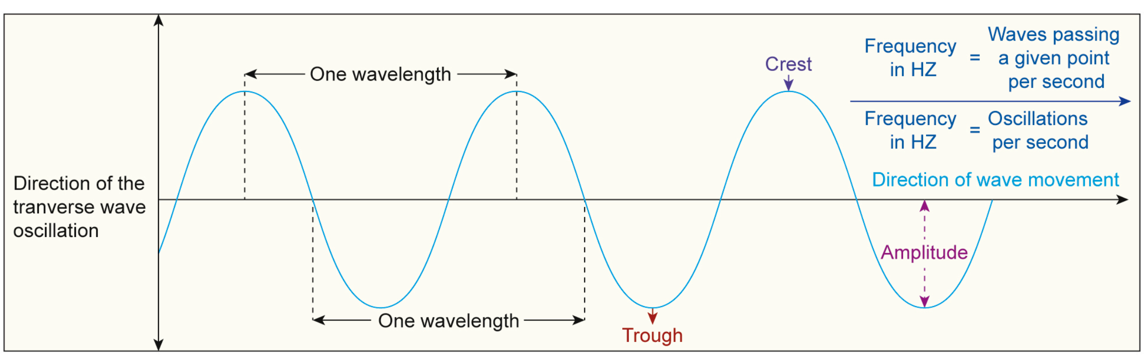
[50] Note, however, that transcranial magnetic stimulation (TMS) studies have shown latencies between 25-50 ms are physiologically important (e.g., Muckli et al., 2005); hence, the temporal parameters of the following illustration provide *minimal* temporal parameters. Longer latency explanations are both plausible and probable.

Regarding (ii), neural models and experimental evidence show that feedforward and feedback signals are generated by activity in V1 and V5, respectively, which function at different oscillatory rates (Kiebel et al., 2008; Donner and Siegel, 2011; Bastos et al., 2015), on account of being generated in different cortical layers (van Kerkoerle, 2014; Petro and Muckli, 2017; Scheeringa and Fries). This oscillatory difference is critical because there is strong support for the idea that oscillatory dynamics set information processing boundaries by determining the duration of neural integration windows (Metzinger, 1995; Herzog et al., 2016; van Wassenhove, 2017). The discrepancy in neural integration window duration in turn generates discrepancies in the rate of signal propagation. More concretely, experiments show that feedforward signals (from V1 to V5) tend to operate at gamma frequencies, while feedback signals (from V5 to V1) tend to operate at alpha and low-beta frequencies (Buffalo et al., 2011; Xing et al., 2012; Markov et al., 2014; Bastos et al., 2015; Scheeringa and Fries, 2019).[51] The foregoing implies that feedforward signals from V1 are generated by integrating neural activity over shorter time scales (~25ms) than feedback signals from V5 (~50-125ms). For concreteness, I will use 25ms to quantify oscillatory integration windows in V1 and 60ms in V5.[52] (See fig. 6 (b)).

[51] "Feedforward projections originate predominantly in supragranular cortical layers and terminate in layer 4, and this pattern is reflected in inter-laminar and interareal directed gamma-band influences. Thus, gamma-band synchronization likely subserves feedforward signaling. By contrast, anatomical feedback projections originate predominantly in infragranular layers and terminate outside layer 4, and this pattern is reflected in inter-laminar and interareal directed alpha- and/or beta-band influences" (Scheeringa and Fries, 2019).

[52] It is also telling that Vetter et al. (2015) found that the benefit of detecting predictable (as opposed to unpredictable) stimuli during AM tasks was abolished when TMS was applied to V5 at an average latency of 33ms pre-stimulus. Given my assumption that signals to V5 take 30 ms, this result dovetails nicely with my use of 60ms as a mean duration for V5 signal integration. That is, the disruption of at least one 60ms integration cycle in V5 is nicely congruent with these experimental results.

I will begin with a quick review of oscillatory dynamics (see Fig. 4). The time it takes for a single oscillation is called its period, while the number of oscillations per unit time is its frequency. So the higher the frequency is, the faster the oscillation rate is, and vice versa. An oscillation, plotted as a sine wave, will exhibit both a peak and a trough while cycling through its period. The instantaneous position of an oscillation relative to its period is an oscillation's phase. So, for example, the phase might indicate the peak, the trough, or something in between. The peak and trough are deviations from a central average value of the oscillatory amplitude, and the greater the deviation or displacement, the greater the oscillatory amplitude. Oscillatory amplitude corresponds to the strength of the collective post-synaptic current being measured (see below). This roughly relates to the number of synchronous neurons at a given time (see below). The amplitude rises considerably during the oscillatory peaks and falls below its central, average value during oscillatory troughs.



The basic properties of wave

Figure 4: Oscillatory frequency is 1/wavelength. Amplitude is represented by the voltage displacement on the vertical axis. And phase is the instantaneous position of an oscillation relative to its period (Piper, 2019).

In more detail, oscillatory peaks conventionally correlate with intervals of enhanced neuro-electrical activity (depolarization) in large neural populations, while troughs conventionally correlate with intervals of diminished neuro-electrical activity (hyperpolarization) in large neural populations. Measurable neuro-electrical activity appears to be a product of synchronized post-synaptic currents – i.e., changes in membrane potential in post-synaptic neurons – rather than simply action potentials (Nunez and Srinivasan, 2005).[53] Hence, EEG, the most typical measurement of neuro-electrical activity, reflects the summation of thousands of post-synaptic ionic currents. Note that without synchronization of these currents, the electrical signal would be too weak to separate from mere noise; hence collective coherence within a neural population is key.

It is common to think of peaks as corresponding to intervals of greater activity and/or neural sensitivity – i.e., intervals within which neural communication is enhanced (cf. Fries, 2005), with contrary assignments can be given to oscillatory troughs. But this is only convention, since the effect of an oscillation on the ensuing oscillatory dynamics of the networks in which it's embedded will depend on the spatiotemporal distribution of the network's excitatory and inhibitory circuits. For our purposes, what is important is to understand that there are *select intervals during an oscillatory period, quantifiable by*

[53] There are a number of methods for measuring neuro-electrical activity, including EEG (measures voltage from scalp), MEG (measures magnetic field from scalp), ECoG (measures voltage from brain surface) and LFP (measures voltage from within brain tissue). Perhaps surprisingly, experiment has shown that most measures of voltage vary only weakly with action potentials, but rather are largely a measure of synchronized post-synaptic potentials – i.e., changes in ion flow between neurons (that, when summed, can generate measurable electrical fields) (Niedermeyer and Lopes da Silva, 1998; Nunez and Srinivasan, 2005). An explanation for this finding is that cortical tissue filters out high frequencies associated with action potentials, while low-frequency electrodynamics, like post-synaptic currents (also called "graded potentials") can travel much further distances without significant attenuation (Destexhe and Bedard, 2013).

oscillatory phase, when neural communication is enhanced/decremented. Given my just mentioned caveat, by convention, in this manuscript, I will refer to these as oscillatory peaks/troughs.

ROM theory, then, holds that oscillations defined by the foregoing parameters can be integrated through signal multiplexing – essentially by forming larger circuits whose complex rhythms allow for the participation of multiple oscillations from different frequency bands – eventually into reentrant circuits: circuits whose feedforward and feedback sources reciprocally affect each others signaling and connectivity (resulting in the formation of a non-linear local system).[54] Those are the basics of the view; I now turn to the AM model.

As a way of preparing for the more complicated demonstration to follow, Fig. 5 provides a quick schematic of how the relationship between V1 feedforward and V5 feedback circuits can account for the most basic temporal phenomena. And Fig. 6 provides an illustration of basic latencies justified above, as well as illustrates the steps of the model.

[54] Reentrant circuits connect neural regions and allow them to have evolving influence on each other's suprathreshold activity and local connectivity (Edelman, 1987; Edelman and Tononi, 2000). These have been speculated to be part of the neural machinery necessary for conscious representation (ibid.; Arstila, 2016; Adapa, 2017).

BASIC TEMPORAL EXPERIENCE	NEURODYNAMICAL CIRCUIT ACTIVITY
1. Stimuli X and Y are experienced as simultaneous or fused (e.g., two flash fusion).	1. Reentrant multiplexed circuit processes X and Y in the *same* feedforward *and the same* feedback signals.
2. Stimuli X and Y are experienced as asynchronous but their order cannot be reported beyond chance – called "pure succession" by Arstila (2017).	2. Reentrant multiplexed circuit processes X and Y in *distinct* fast feedforward signals but are integrated into the *same* slower feedback signal.
3. Stimuli X and Y are experienced in succession.	3. Reentrant multiplexed circuit processes X and Y in *distinct* feedforward *and* feedback signals.

Figure 5: An illustration of how latency differences stemming from feedforward and feedback circuits offer intuitive explanations of the most basic temporal phenomena.

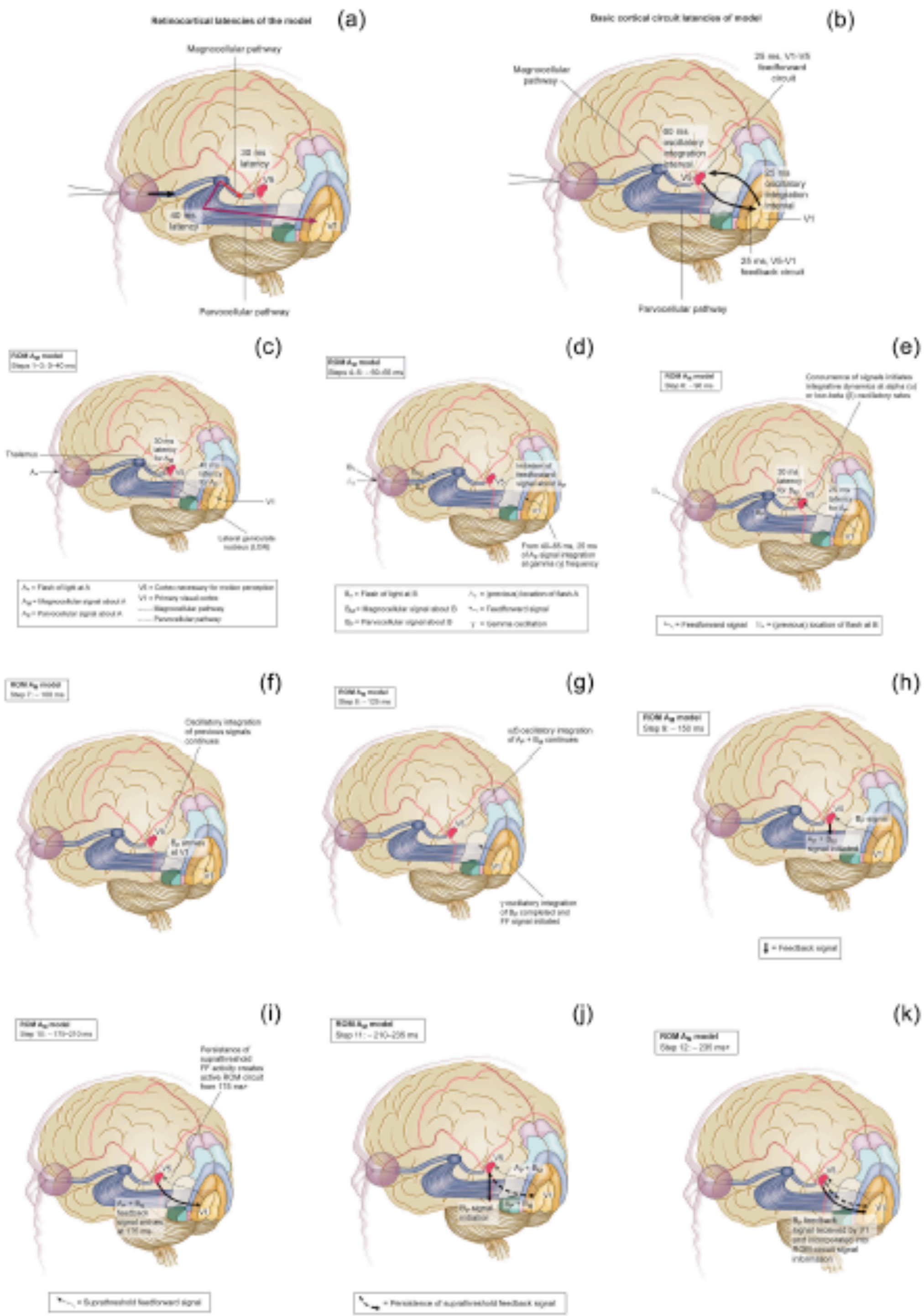


Figure 6: These figures provide a time-stepped sequence of the AM model to illustrate an ordinal isomorphism between brain time and experiential time (Piper, 2019).

4.3. The ROM account of AM

With these points in mind, an empirically-supported ROM extensionalist explanation of apparent motion (AM) is the following.[55]

(1) At t_0 – i.e., 0 ms – stimulus A is flashed and activates the retina. Signals are sent down both parvocellular and magnocellular tracks, with the activation in the magnocellular pathway being significantly weaker than within the parvocellular due to the stationarity of stimulus A.

(2) Around 30 ms, a weak magnocellular signal about A reaches V5, insufficient on its own to generate a suprathreshold feedback signal to V1.[56]

(3) Around 40 ms, a strong (suprathreshold) parvocellular signal about A reaches V1 that initiates a local phase reset[57] in V1, commencing the generation of a feedforward

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[55] I am grateful to Valterri Arstila for his (2016a) discussion of apparent motion. Although our views are strongly at odds in multiple respects (cf. Arstila, 2016b/2017), I endorse (1) his advocacy of the importance of reentrant circuitry for explaining AM and (2) the chronological explanatory format he employed.

[56] This is because V5 was (in typical experimental conditions) around resting potential, even if subject to subthreshold fluctuations. V5, once moved from resting potential, will be more easily depolarized at certain ISIs, and less easily at others (cf. Fries, 2005; Buzsaki, 2006; Romei et al., 2016).

[57] As I explain in detail in the next chapter, the relationship between the phases of different oscillations plays a central and crucial role in ROM theory. There is a vast amount of experimental evidence showing that these phase relationships, and especially types of coordination among oscillatory phases, are critical for understanding both cognition and consciousness (e.g., Demiralp et al., 2007; Schroeder et al., 2009; Handel and Haarmeier, 2009; Canolty and Knight, 2010; Tort et al., 2010; Voytek and Knight, 2015; Herring et al., 2019). A *phase reset* among phases (of oscillations x, y and z, e.g.) is a moment in time when the variability between the phases of x, y and z disappears and oscillations x, y and z restart from a shared time point.

signal. Since V1 feedforward activity occurs at gamma frequencies, the processing of the feedforward signal occurs over the next 25 ms. (See fig. 6 (c)).

(4) At 60 ms, stimulus B is flashed, activating the retina and initiating magnocellular and parvocellular signal cascades towards V5 and V1.

(5) At 65 ms, a feedforward signal integrating the V1 activity over the prior 25 ms is sent towards V5. This signal contains information about A carried by the parvocellular channel, initially processed by the retinal cones (See fig. 6 (d)).

(6) At 90 ms, V5 receives (i) feedforward parvocellular information about A from V1 *and* (ii) retinotopic magnocellular signals about B. This temporal synchronization initiates the generation of a feedback signal integrating activity in V5 from those two signals.[58] (See fig. 6 (e)).

(7) At 100 ms, a strong parvocellular signal about B reaches V1, initiating a new integration over the next gamma cycle (See fig. 6 (f)).

(8) At 125 ms, a feedforward signal carrying parvocellular information about B is sent towards V5, carrying the information about the flash at B initially registered by the retinal cones. (See fig. 6 (g)).

[58] The temporal synchronization of afferent (incoming) signals involves the phase alignment of signals (Gruber et al., 2014) resulting in the creation of a temporal integration window, the results of which are sent as a feedback signal to V1 (cf. Vetter et al., 2015; Edwards et al., 2017; White, 2018).

(9) At 150 ms, a feedback signal integrating the V5 activity over the prior 60 ms (involving the parvocellular information about A and the magnocellular information about B) is sent towards V1. V5 also receives a feedforward signal about B from V1, but, critically, it arrives too late to be included in the feedback signal. The integration of a new feedback signal is initiated by this second feedforward signal from V1. (See fig. 6 (h)).

(10) At 175 ms, V1 receives the first feedback signal from V5. The signal contains both (i) detailed information about A's visual features *and* (ii) relative positional information about B – though without any parvocellular visual information about B. Since it integrates both (i) and (ii) into one multiplexed signal, it serves as the basis for the experience of a light with A's characteristics moving towards B. Since it doesn't integrate any parvocellular information about B, it doesn't involve a representation of B's actual location or features. Hence, it serves as the basis for the beginning of the apparent motion experience.[59] Importantly for the larger view developed below, this is because the reception of feedback from V5 marks the completion of a reentrant processing circuit. As that circuit continues to be active, the AM experience continues. As the circuit carries different information, experience changes in step. (See fig. 6 (i)).

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[59] It might be thought that since there is information in the system about A and B prior to 175ms that this implies this model involves a delay. As regards apparent motion this is incorrect, since the model requires the completion of a V1-V5 reentrant oscillatory multiplexed circuit for conscious experience of AM, and 175ms is the fastest this can occur (under the empirically-based assumptions given). (The multiplexed oscillatory dynamics are seen in the integration of signals of different frequencies, while the return of information to V1 is what completes the reentrant circuit. We know return to V1 is important because ablation (temporary via TMS or permanent) of V1 prevents conscious visual representation.) But what if the flash at A was unaccompanied by B? Does it still take 175ms for conscious experience of A? See the main text below for discussion.

(11) At 210 ms, V5's feedback processing of parvocellular information about B is complete, and a signal is sent towards V1. Through this period, the subject experiences the continued motion of light towards B.[60] (See fig. 6 (j)).

(12) At 235 ms, V1 receives the feedback signal from V5 about the detailed visual properties of B (and not just relative position). The integration of this parvocellular information into the existing reentrant circuitry corresponds to the experience of A's movement ending at B with the visual properties of B. Since there was no further stimulus, motion processing begins to end. The subject experiences the properties of B for a time determined by its stimulus salience (intensity of luminance/color/etc.), which determines the depolarization duration of B's neural vehicles (Irwin and Yeomans, 1991), and the experience of apparent motion ends as B fades, with the duration of the experience of B depending on stimulus intensity foremost. This last point is extremely critical. The ROM model involves the idea that the experience continues as long as the reentrant circuit remains active. If the information it is carrying changes, then experience will change. So the duration of experience is determined not by the exact numbers given above, but by how long the ROM remains depolarized (actively carrying signals).[61] And the content of experience is determined by what information the ROM circuit carries, which in this case would be the fading of a light at location B (See fig. 6 (k)).

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[60] This has been confirmed by TMS experiments (briefly hyperpolarizing local cortical regions) to disrupt this interval (Muckli et al., 2005).

[61] In vision science, this corresponds to a well-known phenomenon called "persistence of vision," in which a brief stimulus leads to a depolarization that far outstrips it, causing a experience of the stimulus well beyond its objective occurrence.

4.4. Discussion of the ROM AM Model

Let me first clarify why this is a ROM model of AM. The role of reentrant circuits plays a prominent role in the explanatory steps above, and so is obvious. Oscillatory dynamics are critical because they determine the temporal dynamics according to which signals are generated and integrated (or not) in the reentrant circuits. That is, oscillatory dynamics set the basic integration windows by which the signals realizing visual representations occur, and hence are foundational. Lastly, multiplexing is critical in that the reentrant circuit that generates the AM experience only realizes conscious representational content once they harmoniously integrate the multiple frequency signals (alpha and gamma, as indicated) generated by the feedforward and feedback activity. I turn now to how the ROM model of AM is an extensionalist one.

Looking at each processing step, notice that *the order and extent to which multiplexed oscillatory activity is integrated into the formation and continuation of a reentrant circuit resembles the order of temporal representational content experienced*. Notice how the temporal representational content changes over time in concert with changing oscillatory circuit properties. Within an interval beginning around 175 ms post-initial-stimulus, the circuit processes a cycle of content involving A moving towards B. In the ensuing interval up to 235 ms, the circuit content involves a shift of features from those of A to those of B while smoothly continuing the spatial trajectory towards B. And beginning at 235 ms, the AM experience culminates in a representation of location B. Again, the experience doesn't cease at 235ms unless there are strong hyperpolarizing influences. As mentioned, it continues as long as the ROM circuit remains depolarized.

Key empirical support comes from MEG studies on the timing underlying the emergence of visual consciousness:

> Using decoding to analyze the MEG data, we identified the time at which the neural signal started to differ between trials where visual consciousness was present, and where trials where visual consciousness was not evident. We found that visual consciousness is characterized by an increasing decodability of stimulus information, emerging around 180-230 ms post-stimulus onset. (Mai et al., 2019).[62]

These representational contents correspond to, and are therefore plausibly explained by, the hierarchical integration of oscillatory dynamics within reentrant circuit signals, signals that can explain the content of AM (i.e., A->B) through resemblance.[63]

A question arises as to the timing of the AM experience. On the presented model, A is not experienced until 175ms after stimulus registration. But what if A is presented alone? Would visual recognition still take 175ms of processing, even if V5 wasn't relevant to generating the representational content (of a single unmoving flash)? This is a question that illuminates how the model, as mentioned above, is technically incomplete.

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[62] The experiment involved presenting stimuli at perceptual threshold (via a backward masking paradigm in which a subsequent stimulus masks an earlier one) while recording MEG data from relevant regions of interest (ROI). The MEG data was used to predict whether the subject demonstrates (through forced-choice exam) or reports visual consciousness. Using multivariate pattern analysis, the researchers discovered clear markers of visual consciousness decodable in the MEG data emerging between 180-230 ms. As indicated, this dovetails beautifully with the presented model's predictions.

[63] An anonymous reviewer for my (2019) publication of this model in *Consciousness and Cognition* asked "I don't follow why this story *necessarily* involves representation of motion through resemblance. Why couldn't an anti-resemblance theorist say that it involves first a representation of the object as at A and moving towards B, and then a distinct representation of the object moving towards, and arriving at B – two separate representations at different times, both involving representation of motion by some means other than resemblance?" (my italics) This question deserves a few replies. First of all, my dialectical aim is not to prove the incoherence of my model with anti-resemblance views. Necessity is too high a bar at this stage of development (both empirically and philosophically). Rather, given the state of discussion, oscillatory frameworks are usually thought to imply atomist views, and I hope to show this inference can be resisted. I would like to add, though, that a resemblance story is very intuitive here, and so plausibly deserves to be the default position. Also, a resemblance story is explanatory in a way an anti-resemblance story can't be. That intuition is a foundational one for the extensionalist, and one she shouldn't give up (cf. Dainton, 2010).

As mentioned, a full ROM model would require, among other things, V1-LGN reentrant circuits (and V5-LGN circuits). These are omitted to prevent unwieldiness of demonstration and discussion, but the point deserves some ink.

On ROM, the duration of completion of the V1-LGN reentrant circuit is what determines the latency for conscious representation of a single flash. Signal speeds from the LGN to V1 are not known, but we can derive a speculative answer with two assumptions. First, that the duration of LGN-V1 signaling is roughly half that of retina-V1 signaling, and, second, that there is parity of feedforward and feedback signal speed, as appears to occur in the cortex. With these assumptions in hand, this would place the fastest possible conscious recognition of a single flash at 40+20+20 = 80 ms. This is based on the pre-potentiation of LGN such that it is immediately ready to return a signal. Obviously, given how the feedback signal from V1 to LGN relates to the phase of ongoing LGN activity, there can be substantial latencies. During waking, the LGN usually oscillates at alpha frequencies (Hughes et al, 2004). So, if, for example, the V1 signal arrives at the beginning of an alpha integration cycle, then the latency to conscious representation would be up to 40+20+100+20 = 180ms (cf. Mai et al., 2019). Critically, this is only 5ms difference from the 175ms latency given for AM, a difference that would be subjectively inaccessible. To take a median case, where the signal from V1 arrives in the middle of an alpha cycle, and was incorporated into a feedforward signal back to V1, the timing might be: 40+20+50+20= 130ms. In such a case, there would be, technically speaking, conscious experience of A prior to the experience of AM, but the ensuing V1-V5 dynamics would transform the extremely brief (~45ms) experience of the flash at A into an experience of AM. Personally, I do not find this phenomenologically implausible.

One, this is a difficult (if not impossible) difference to introspect, and, two, it would even help account for variations in AM experiences. It is also important to point out that positing conscious visual representation of a flash between latencies of 80-180ms coheres nicely with other theoretical speculations (e.g., Eagleman and Sejnowski, 2000).

Notice that in neither case is there a delay. The different latencies are due to the fact that different tasks and stimulus conditions change which circuits instantiate ROM. Obviously, more complex circuitry requires a longer integration period. This harmonizes very nicely with numerous experiments showing that more complex representational content requires longer unconscious processing for its realization.

To return to the basic extensionalist idea: because different types of visual stimuli (motion versus shape and color, e.g.) preferentially activate distinct neural pathways, there is an empirical explanation for the "illusion" consistent with vehicle-content isomorphism. In a bit more detail, if latencies for motion stimuli are shorter than those for shape and color, so motion stimuli can reach motion processing centers more quickly than shape and color stimuli can reach relevant processing areas (Bullier, 2001; Chen et al., 2007), then the prepotency/priming of the motion areas can affect the processing of shapes and colors (Wibral et al., 2009). In theory, this could explain two observations about AM, thus accounting for it. One, motion towards B is experienced before detailed location information about B because of the lower respective latency of activation of motion processing centers vis-à-vis those that process detailed visual information. Two, apparently out-of-order vehicle/content relations can be shown to be in-order once the fast-tracking of motion information, due to the priming of representational pathways by the earlier activation of motion areas, is taken into account.

This fits most naturally with an extensionalist explanation of AM because the temporal order of neural processing determines and explains the order of temporal phenomenology. I.e., there is "topological mirroring" between brain time and experiential time. As this model shows, the ordinality of temporal representational content resembles the order of ROM neurodynamics unfolding and developing in and through time (Dainton, 2010; Phillips, 2014; Rashbrook-Cooper, 2016).

Critically, this model appears to be more than just an extensionalist explanation of AM. As a version of a differential latency view, it can serve as a foundation for a general extensionalist account of temporal illusions (cf. Bachmann, 2013). Although there isn't space for this discussion, notice that the perceived location of B depends upon the temporal properties of the relevant circuits. If there is some delay/extension or speeding/truncation of relevant dynamics, the experience is extended or truncated in turn (Baldo and Caticha, 2005; Wutz et al., 2015). Hence this model potentially explains visual displacements characterizing other illusions – like the flash-lag effect or Frohlich effect, e.g. – that have been the main method of undermining extensionalism (Grush, 2007; Dainton, 2010). In the flash lag illusion and Frohlich effect, for example, the aforementioned dynamics show how movement information can be incorporated earlier than positional information. It is the completion of a reentrant circuit for motion incorporating delayed-latency (static) positional information that plausibly produces the visual displacement characterizing both effects.

4.5. Conclusion

This chapter has presented a coherent extensionalist model of AM that shows arguments against extensionalism based on temporal illusions are too hasty. My defense of extensionalism relies on a neurobiologically inspired differential latency account. This is a considerable merit, as it places the defense on sounder empirical footing than is possible in the context of merely descriptive philosophical debate.

Time to introduce the full ROM theory of the specious present.

[Parts of this chapter were published in 2019 by the journal *Consciousness and Cognition*. The dissertation author was the primary investigator and author of this paper.]

CH 5: The ROM Theory

5.1. Motivation

The motivation behind ROM theory is formulating a neuroscientifically accurate theory of the specious present that can bear on independent philosophical debates about the same. The neural machinery characterizing ROM theory has a great deal of neuroscientific support. What isn't so clear is how the model should help adjudicate philosophical preferences. After describing the mechanics of the model, I will focus on how ROM is meant to serve as an R-theory. My goal is not to refute NR-theories. Rather, I wish to shift the burden to the NR or cinematic theorist by presenting a coherent and plausible view that has more empirical support than any rival view. To the science.

5.2. The neuroscience of ROM theory

Before delving into the details, an analogy might be helpful. Essentially, the model postulates that the brain activity realizing coherent mental representation and phenomenal consciousness (a fortiori, temporal representation and temporal consciousness) can be usefully compared to an active orchestra. Roughly speaking, music is a product of various auditory *resonances* (in rhythm, pitch and timbre, e.g.) amongst the parts of the active orchestra. Analogously, the ROM model formalizes the idea that coherent mental representation and experience is the product of various resonances (i.e., multiplexing[64]) between the phases, frequencies and amplitude parameters (oscillatory parameters) of reciprocally connected information-processing (i.e., reentrant) brain circuits.[65] A very important analogical point for what follows is that, in a coherent orchestra, different timbres, pitches or rhythms can alternate in serving as a leitmotif that grounds other timbres, pitches or rhythms. Similarly, in the brain, different frequencies, phases or amplitudes can play the same role – serving as a *root* frequency, phase or amplitude to which other frequencies, phases or amplitudes coordinate (see below). Although I think this analogy is helpful for more than illustrative purposes, and carries legitimate explanatory power, I will not defend this latter claim here. Regardless, keeping the foregoing in mind during the next few sections will hopefully be useful.

5.2.1. ROM: Temporal Representational Vehicles in the Specious Present

As the acronym suggests, ROM theory is characterized by three levels of vehicular structure. The most basic vehicular level is oscillations. There is a surging view in modern neuroscience that oscillations – rhythmic fluctuations in neural excitability characterized by (i) phase, (ii) amplitude and (iii) frequency parameters (see figure 3) – are key role-players in neural computation and conscious representation (e.g.,

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[64] Neural multiplexing is a form of complex neural synchronization involving the harmonization of multiple oscillatory components into an integrated signal. See below.

[65] Although I won't unpack it here, the ROM model also offers an explanation for variance in the complexity of mental contents in terms of the complexity of ROM dynamics, where "complexity" can be roughly unpacked along the lines of fractal dimensionality or mutual information transfer (Mandelbrot, 1980; Edelman and Tononi, 2000; Piper, 2012). This, too, is paralleled by the orchestra case, in which the complexity of music is roughly proportional to the complexity of time-evolving resonances between the auditory products (rhythms, pitches and timbres, e.g.,) of the orchestra as a whole. Conversely, an absence of complex resonance in orchestral dynamics or the brain tends to generate mere noise in the first case and/or unconsciousness in the second.

Fries et al., 1997; Engel et al., 2001; Buzsaki, 2006; Melloni et al., 2007; Lakatos et al., 2008; Canolty and Knight, 2010; Mathewson et al., 2012; Helfrich et al., 2014; Spaak et al., 2014; Kosem et al., 2014; Thut, 2014; Voytek and Knight, 2015; VanRullen, 2016; Samaha and Postle, 2017; Ronconi et al., 2017; White, 2018).

The studies just cited all show ways in which conscious representation appears shaped by oscillatory dynamics. For example, phase shifts have been argued to realize a temporal code structuring representation in general (Kosem et al., 2014; Calderone et al., 2014; Maris et al., 2017; Van Wassenhove, 2017); amplitude shifts appear to fundamentally underlie changes in neurodynamical intensity and hence the possibility of conscious representation simpliciter (Rusalova, 2006; Purdon et al., 2013); and frequency shifts strongly correlate with shifts in task- and content-dependent processing, which is unsurprising, since different cortical regions have distinct resonant oscillatory frequencies (Buzsaki, 2006; Rosanova, 2009; Samaha et al., 2017; Ronconi et al., 2017). These are big ideas that cannot be sufficiently defended here. Thankfully, there is a large empirical literature supporting each of those speculations. However, though I endorse all of those suggestions, their truth is not necessary to warrant the arguments in this dissertation. What is critical, though, is the recognition of the degree of empirical support for the idea that representational contents sensitively depend upon, perhaps even supervene on, oscillatory dynamics.

It is interesting to see some of the independent support other researchers have forwarded for elements of the basic vehicular picture I outlined above. ROM formalizes and extends the idea that "cortical oscillations provide the *temporal reference frame* on which perceptual timing relies" (Kosem, 2014; p. 9). This is obviously congruent with

ROM, expressing the idea that the temporal structure of experienced time depends on the temporal structure of brain time.

In a large-scale review of the neuroscience of temporal consciousness, Michael Cohen (2011) helpfully explains the role of oscillations (the heart of ROM theory) in this way: "Perhaps *oscillations…act as an organizing filter* or selector for different populations of cells that actually encode/process information…" (2011; p.12) Since oscillations are necessarily temporal, this idea implies that the organizing filter for mental representation is essentially temporal, showing a kind of resemblance characteristic of extensionalist views.

And Virginia van Wassenhove (2017), independently developing her own views on temporal consciousness, writes, "…*oscillatory brain activity and re-entrant processes make time a function of itself* within the confinement of a given neural circuitry or network" (p. 183).[66] It is notable that chief defenders of anti-resemblance views (Grush, 2007/2015; Lee, 2014) have articulated the argument between resemblance and anti-resemblance views in terms of whether brain time is, or is not, used to represent (experiential) time. In this context, van Wassenhove's comment is directly supportive of ROM and directly at odds with anti-resemblance theories.

Returning to the explication of the ROM model, although oscillations are the ground of the model, they are insufficient to realize conscious experience, as shown by absence seizures and slow wave sleep; furthermore, consciousness doesn't appear to be

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[66] It is important to note that my treatment is not at odds with that of van Wassenhove (2017) when she argues that higher-level cognitive representations of time require a distinct explanatory approach. I agree with that view. My ROM treatment based on temporal integration windows instantiated by oscillatory coherences is an explanation of immanent *and not conceptual* temporal consciousness.

exclusively correlated with a single oscillatory band (cf. Buzsaki, 2006; Piper, 2012; Piper, 2015; VanRullen, 2016; Gallato et al., 2017).

Rather, the emerging picture is that oscillatory multiplexing is also required. As mentioned in a footnote above, neural multiplexing is a form of complex neural synchronization involving the harmonization of multiple oscillatory components into an integrated signal (Akam and Kullmann, 2014; Jensen et al., 2014; Calderone et al., 2014; Gu et al., 2015; Tomassini et al., 2017; Ronconi and Melcher, 2017). (The harmonization of oscillatory components occurs by various forms of oscillatory synchronization, discussed in the next paragraph.) A multiplexed signal carries information about multiple sources and can be, but need not be, selectively decoded by different receivers. To understand this last point, just consider how different antenna tunings will select different information channels from a broadband signal (radio and dish-tv systems are quotidian examples). The focus in this manuscript is on how multiplexing allows for the integration of distinct signals into a unified, broadband signal (which carries information about each distinct signal in an integrated manner). Because multiplexing involves the simultaneous encoding of multiple signals, it is a plausible mechanism to account for the integration of multiple representations (e.g., represented properties) (Lankarany et al., 2019). ROM postulates that multiplexing is a further necessary, but singly insufficient, condition for conscious representation simpliciter (temporal properties or otherwise).[67]

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[67] Because it requires the integration of multiple signals for conscious representation, it shares features with the global workspace and information integration theories of consciousness. And because ROM requires recurrent connections, it shares key features with the recurrent processing theories of conscious content. See section 5.3.3. for a discussion of these relationships. There I will argue that ROM provides a neurobiological mechanism that can, in effect, harmonize these different theories by reference to the extent of reentrant oscillatory multiplexing involved. For example, local recurrent connections are sufficient for non-reflective conscious experience, on both recurrent theories and ROM, while global recurrent connections are necessary for introspective report, on both global workspace theories and ROM. As seems typical in theoretical studies, each extant theory emphasizes a particular part of the whole.

Multiplexing is a term for a class of mechanisms that can arguably help explain how multiple oscillatory signals could be harmonized to eventually realize the simultaneous representation of multiple properties (as occurs during all conscious states/experiences[68]); hence, multiplexing is employed as a component of a larger representational vehicle (i.e., ROM). There are six basic kinds of multiplexing (Jirsa and Muller, 2013), comprised of pairwise combinations of the 3 basic oscillatory components: phase-amplitude coupling (PAC), phase-phase, phase-frequency, frequency-amplitude, frequency-amplitude and amplitude-amplitude.

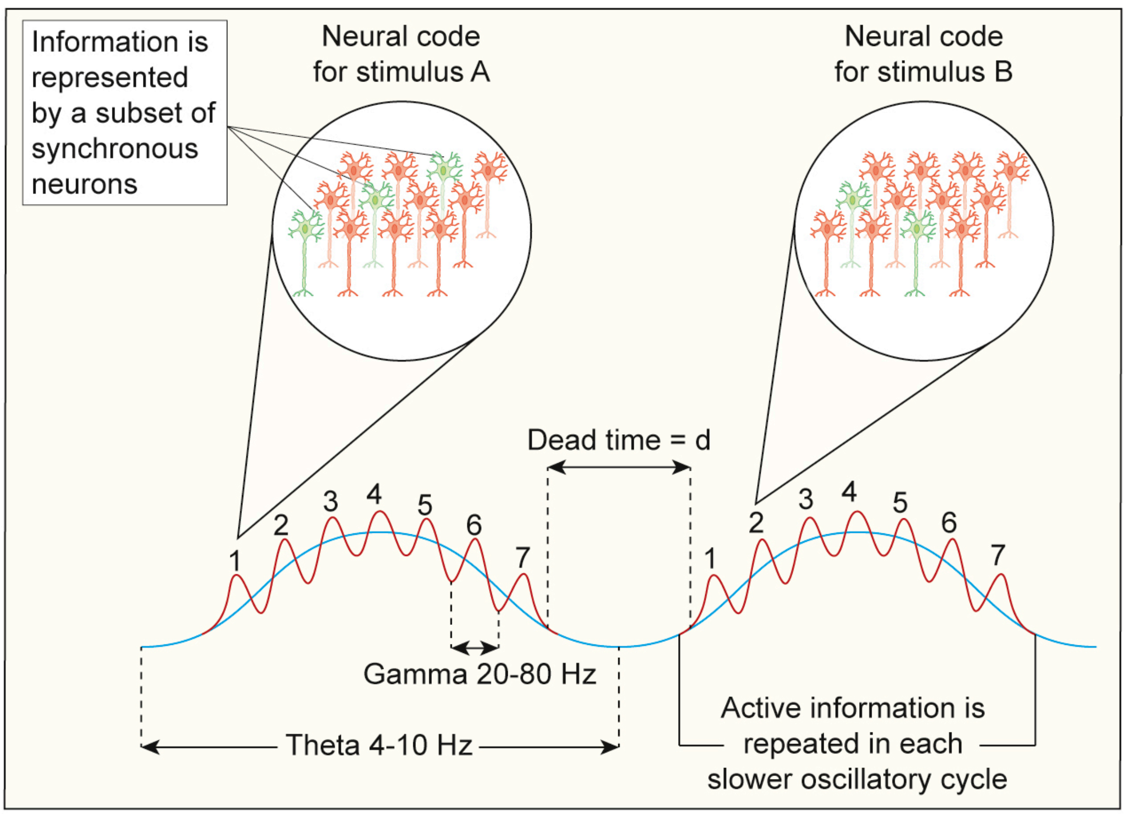

Figure 7: An idealized illustration of phase amplitude coupling (PAC) (Piper, 2019).

[68] There is no reliable evidence for conscious states/experiences comprised of only one, single representational content/property.

By far, the most discussed example is phase-amplitude coupling (PAC), where the phase of one oscillation modulates in concert with amplitude fluctuations in another – see Figure 7. Typically, PAC is characterized as a coupling between distinct oscillations in which the phase of one oscillation (usually lower frequency) increases the amplitude of a distinct (usually higher frequency) oscillation through part of the low-frequency oscillatory period (peak), and, conversely, can (but need not) decrease the amplitude through part of the low-frequency oscillatory period (trough). In sum, the effect of PAC is that phase components of one oscillation modulate the synchrony and strength of a distinct oscillation, and this increased synchrony is measured as an amplitude increase. Usually, this will mean: the phase of a low frequency oscillation temporally regulates the amplitude (and hence signal strength) of higher frequency oscillations, thereby controlling information flow in the brain (Munia and Aviyente, 2019).

It is interesting to note that bi-directional causality should be presumed possible. While it is commonly assumed that phase definitely modulates amplitude in PAC, the possibility that amplitude modulates phase has been understudied. Nevertheless, amplitude fluctuations are a signature of fluctuations in neural synchrony, and bursts of synchrony are one mechanism for generating phase resets (Canavier et al., 2015). Thus, transient increases in oscillatory amplitude should be able to generate various phase modulations (phase reset, phase shift or phase alignment). That is, amplitude increases in higher frequencies – due to increase synchrony in higher frequencies – can, and will in certain contexts, reset the phase of lower frequencies. Given that phase modulation as a result of amplitude gain is a very natural mechanism for neural organization, it would be more than odd if the brain didn't put it to some information-processing use. While nothing specifically hinges on this point in what follows, when in doubt about mechanisms of neural integration, it seems wise to take a liberal point of view, if simply from an evolutionary point of view.

As regards PAC, there is significant experimental evidence correlating phase amplitude coupling with performance variability in widespread task conditions (Demiralp et al., 2007; Schroeder et al., 2009; Handel et al., 2009; Canolty and Knight, 2010; Tort et al., 2010; Voytek and Knight, 2015; Herring et al., 2019), which suggests the importance of multiplexing in general, but of PAC specifically. In this manuscript, I will be exclusively concerned with PAC multiplexing, but the other forms are by no means excluded from future incorporation into ROM theory. There will be no further discussion of the other 5 types of multiplexing here, however.

When investigating how the harmonization implicit in multiplexing works, research and reasoning strongly suggest that the signal synchronization underlying multiple signal integration (Varela et al., 1991; Fries, 2005; Voytek and Knight, 2015) sensitively depends on the relative frequencies of the signals being multiplexed. Consider the orchestra analogy. Just as slower rhythms in a complex rhythm serve as organizing structures for grouping faster rhythms (and keeping them "on beat"), so too it appears that slower frequency oscillations in the brain help organize faster frequency oscillations, helping to keep them synchronized. The import of this is twofold: (1) slower frequencies are essential for multiplexing and (2) the slower the organizing oscillation, the more extensive the possible synchronization of faster rhythms.

As Buzsaki (2006) explains, an important feature of multiplexing is that:

> …the size of the activated neuronal pool is inversely related to the frequency of synchronization…[because] when the rhythm is fast, only small groups can follow the beat perfectly because of the limitations of axon conductance and synaptic delays….[t]hus, the slower the oscillation, the more neurons can participate; hence, the integrated mean field is larger…[moreover]…perturbations occurring at slow frequencies can cause a cascade of energy dissipation at higher frequencies, with the consequence that widespread slow oscillations modulate faster local events (p.116-134).

It is worth unpacking this truncated quote. The first point to note is that if you want to synchronize the activity of a lot of semi-chaotic, "dumb" neurons, then you have to provide an organizing cue that is sufficiently low frequency to allow large-scale coordination to a "beat". Achieving large-scale synchronization in a neural network is intrinsically tricky because of the variable and extended latencies between widely separated parts of a network. The larger the network you want to synchronize, the lower the organizing oscillation frequency must be in order to provide a lengthy enough window within which all those intra-network signal latencies can be organized. Hence, slow oscillations are critical to coherently integrating the activity of faster oscillations, and the greater the spatiotemporal extent of a network to be integrated, the slower the grounding oscillation must be. Conversely, slower oscillations allow for the realization of larger neural networks. This is important because, given the receptive field specificity of the cortex, the more disparate the representational content (temporal or otherwise) to be unified, the larger the neural network required to instantiate the requisite vehicular realizers.

To give an example drawn from Buzsaki's quote, imagine trying to get 100 non-musicians ("dumb" neurons) to coordinate drum-beats at 40 Hz (every 25ms) by sending out a 40 Hz signal by which they are supposed to synchronize. Any error in the signal (from either the sending or receiving/processing side) will bloom into a serious communication coherence issue, as well as preclude synchrony of the whole. Even a bit of asynchrony, moreover, will generate further asynchrony as the noise of off-hits will disrupt coordination to the 40 Hz signal. Hence, the result will be cacophony in short order. Compare that to getting 100 non-musicians to coordinate at 1 Hz (every second) by sending out a 1 Hz signal. Not only is the demand much diminished on the timing coordination, but faster signaling (quickly saying "ready-hit!, ready-hit…" etc.) can facilitate coordination as well. Analogously, organizing large numbers of neurons requires a grounding oscillation as slow as possible to be able to accommodate both signal latencies as well as challenges that would be caused by overly stringent timing requirements characteristic of faster frequency signals.[69]

A second point to note in the Buzsaki quote is that not only do standing low-frequency oscillations serve as organizing filters/templates for faster oscillations, but that changes in low-frequency oscillations will cause a cascade of timing shifts in higher frequency signals as a result. Since the low-frequency oscillations provide signals by which faster oscillations will synchronize, changes in the former will shift the timing of the latter. This is an excellent example of a way in which low-frequency oscillations cause significant downstream effects at other frequencies. Since different areas of cortex tend to oscillate at distinct frequencies (Rosanova et al., 2009), this is a mechanism by

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[69] This is very critical, since it offers an explanation for why multiplexing grounded in slower rhythms involves larger spatiotemporal integration and can thus support more complex representational content. This is one of the more powerful ways ROM theory grounds an understanding of the density of representational content in terms of neurodynamical throughput density (cf. Edelman and Tononi, 2000; Dehaene and Naccache, 2001; Piper, 2012). Though a fascinating point, it is one that would take us a bit afield, but the interested reader can look at the cited articles for more on that score.

which areas of the brain that tend to generate slower oscillations (frontal cortex, hippocampus, anterior cingulate, etc.) can modulate the timing of other areas (parietal cortex, thalamus, primary sensory cortex, etc.).

A key (third) point, in addition to those made by Buzsaki, is that there is considerable empirical evidence that attention and basic perception depend on theta, delta, and even slower rhythms. Positive evidence correlates conscious awareness to multiplexing grounded in these rhythms (Lakatos et al., 2008; Doesburg et al., 2009; Schroeder and Lakatos, 2009; Fiebelkorn, 2013; Lisman and Jensen, 2013; Harmony, 2013; Calderone et al., 2014; Arnal et al., 2015; VanRullen, 2016; Heusser et al., 2016; Tomassini et al., 2017), while negative evidence is that non-multiplexed gamma rhythms are present in anesthetized animals (Xing et al., 2012b; Merker, 2013; Ni et al., 2016), which shows that faster local rhythms require the spatiotemporal coordination provided by multiplexing with slower rhythms for conscious experience to obtain. He et al. (2009) explain it like this:

> From a theoretical perspective, information has to be integrated to contribute to conscious awareness, for conscious experience is always a unitary and undivided whole…We suggest that the SCP [Slow cortical potential [i.e., delta oscillation]] might be an optimal neural substrate to carry such information integration across wide cortical areas because (i) its slow time scale allows synchronization across long distance despite axonal conduction delays…(ii) long-range intracortical and corticocortical connections terminate preferentially in superficial layers and thus contribute significantly to the SCP. (p.5).

For my purposes in this manuscript, these three points suggest that the kind of neural networks realizing conscious perception are all grounded by slower oscillatory frequencies capable of supporting a spatiotemporally extended multiplexed network comprised of low-, mid- and higher-level frequencies. Given this stipulation, we can say that ROM instantiates a *hierarchical* model of the specious present, and of conscious representation more generally.

It is essential to note that my AM model in the previous chapter focused on the relationship between mid- and high-frequency oscillations. A full treatment would include their relationship to low-frequency oscillations generated by the frontal cortex and subcortical structures in order to reflect the operation of attention, memory, executive planning and introspective report. The presumption in the model is that AM experience is possible when confined to a network comprising the thalamus, V1 and V5. And even there, I do not cover the role of the thalamus in much detail. All these omissions are due to space and clarity constraints. The critical thing to see is the consonance of the model in ch. 4 and the more general model, which includes low-frequency (e.g., delta rhythms). The model demonstrated the AM experience occurring between at least 175-235ms, and, given strong depolarization, longer durations, say up to 350ms. Compare that with a delta frequency at 3-4 Hz instantiating an integration window of 250-333ms. It is a striking harmony. Critically, empirical work shows that such minor temporal discrepancies are not generally available to conscious awareness, especially concerning intermodal temporal discrepancies (Dixon and Spitz, 1980; Ohki et al., 2016). The latter authors also found that the mechanism of audio-visual integration in a speech detection task was delta and beta oscillatory PAC multiplexing "coordinated through delta phase coherence" (Ohki et al., 2016; p.1). Although AM as discussed doesn't involve multisensory integration, the consonance of the abovementioned studies and the ROM model are obvious, as should be the general coherence of the speculation that the AM model can be expanded to incorporate delta frequencies as the ground integrative oscillations.

The foregoing reflections show that the general ROM theory predicts that the whole AM experience can occur within one specious present, a prediction verified by introspection. Note also that if a low-frequency oscillation is required for conscious experience (AM included), this doesn't affect the temporal relations of the mid- and high-frequency oscillations and hence the representation of ordinality. Nor would it affect the representational vehicles amongst the thalamus, V1 and V5. It would simply integrate them into a conscious experience. A final point (adverting to the discussion above on the latency to experience an isolated flash A) is that if conscious experience requires low-oscillations, then awareness of A occurs at the same time in both cases because they would both be subsumed within the same low-frequency integration window, which is a nice result.

A word must be said about how multiplexing, understood in terms of PAC, should work, given that low-, mid- and high-frequency signals will quickly fall out of phase and be predominantly out of phase – just by dint of their temporal nature. How are oscillations at distinct frequencies supposed to stay phase coherent? The key idea begins with a point already well made: the activity of faster oscillations should be phase coupled with that of peaks in the low-frequency oscillation. A faster oscillation will be phase coupled to a slower if it tends to exhibit regular peak activity during the oscillatory peaks of a slower oscillation. The activity of the faster oscillations during the troughs of the slower oscillations is largely tangential to the phase coupling in question – and for the reason that communication with the slower oscillations is diminished during its trough phases.

So the idea is that what keeps the mid- and higher-frequency oscillations phase coupled to the slower oscillation is that regardless of what oscillatory variation occurs at those higher frequencies throughout their entire periods, there is a phase-alignment such that the mid- and high-frequency oscillations undergo their intervals of maximum sensitivity (their peaks) when receiving driving signals – signals that can entrain the mid- and high-frequencies – from the slower oscillations (cf. Fries, 2005; Voytek and Knight, 2015). This attunement to, sensitivity to, the driving signals from the slower frequencies is what grounds the coherence between activity at various frequency bands. The same idea applies to coupling between slow- and mid- frequencies and between mid- and high-frequencies. In general, the phase of the mid- and high-frequency peaks must correspond to the peak phases of the slower frequency peaks to ensure maximum communication and entrainment to the slower oscillations. ROM is hierarchical because higher-frequencies can be phase coupled with mid-frequencies, which are themselves phase coupled with slow frequencies, generating a *hierarchically coupled oscillatory system*. Given this speculation, the following findings by Chamadia et al. (2019) struck me as particularly impactful:

> Our findings demonstrate that sevoflurane sedation*, a subanesthetic state* from which patients can be aroused to consciousness, is associated with *phase restricted activity of neural oscillations to the trough (π) region of delta oscillations*….taken together, our results provide strong evidence that subanesthetic and general *anesthetic brain states emerge from impaired information processing instantiated by a delta-higher frequency phase−amplitude coupling syntax* (p. 7; my italics).

The conclusion of this EEG experiment studying the transition between consciousness and unconsciousness is that strong multiplexing of higher frequencies (~8-30 Hz (high theta/low alpha to high beta)) to an extreme phase of the delta oscillation is the strongest predictor of unconsciousness. But this is exactly the converse of my claim: that strong multiplexing of mid- and higher-frequency oscillations to the converse phase of delta oscillations is the ROM mechanism by which consciousness obtains.

Now, multiplexing has been proposed as a basic mechanism of feature integration in conscious perception (cf. Metzinger, 1995; Doesburg et al., 2009; Watrous et al., 2015; Helfrich and Knight, 2016). But feature binding can also occur unconsciously (Keizer et al., 2015; Staresina et al., 2015). So, according to ROM, what further neurodynamical activity is needed for conscious representation?

The most influential suggestion on this score is that reentrant circuitry is necessary for consciousness (Edelman, 1987; Edelman and Tononi, 2000; Dahaene and Naccache, 2001; Arstila, 2016; Adapa, 2017). Evidence for this view is that inhibition of reentrant activity through inhibition of feedback connections prevents or inhibits conscious perception and representation (Pascual-Leone and Walsh, 2001; Silvanto et al., 2005; Vetter et al., 2005; Dux et al., 2010), while enhancement of reentrant activity through feedback potentiation increases the sensitivity of conscious vision to the type of stimuli processed by the feedback circuit in question (Romei et al., 2016).[70] Importantly, although the AM model I introduced in the previous chapter only involved visual experience, there is no reason to think that an analogous story cannot be told for other modalities and for multi-modal experiences.

[70] The importance of primary sensory regions is likely due to their denser reentrant connectivity to the thalamus and consequent status as cortical network "hubs" – i.e., regions necessary for integrating the distributed activity of less connected regions (cf. Sporns, 2011).

Let me quickly review the neural machinery – the vehicular dynamics – of ROM theory as a way of preparing to explain how these neurodynamics are relevant to an explanation of the temporal representational content of the specious present. The story begins with oscillations as critical to determining local processing windows for the integration of neural signals. But single oscillations are insufficient for conscious experience, suggesting that phase-amplitude multiplexing is also necessary.[71] Phase-amplitude coupling is a mechanism for integrating multiple oscillatory sources. But mechanisms like PAC can occur unconsciously, so a further requirement is needed. On ROM, this is the instantiation of reentrant circuits, as just mentioned. Ideas along these lines have been previously adduced:

> The studies outlined here raise the speculation that consciousness is a resonance phenomenon in reentrant networks that continuously form and disconnect at multiple spatial and temporal scales. Standing and traveling brain [oscillations] may be manifestations of this process at the very large scales accessible with EEG recordings, providing one mechanism to effect a large scale functional integration of neocortex (Nunez and Srinivasan, 2006; p. 13).

Putting all this together, ROM theory seeks to explain the features of the specious present via the temporal properties of reentrant oscillatory (PAC) multiplexing. Succinctly put, I will argue that the ordinality, extension and continuity of ROM processes accounts for the ordinality, extension and continuity of specious present phenomenology. However, the representational content of the specious present also includes change and discreteness – the notes that form part of an arpeggio, although experienced as unified if played quickly, do not fuse together. As in the shooting star

[71] This shouldn't be taken to imply, in any way, that other kinds of multiplexing aren't occurring. The focus on PAC to illustrate ROM is a function of empirical support and explanatory clarity, but the model can certainly be extended should the evidential justification arise.

example, the specious present contains individuated contents experienced as a perceptual whole. Foreshadowing, ROM also includes an account of the realization of these perceptually unified changes: representational change is realized by PAC phase de-coherence, while representational content unity is achieved via the sustained PAC phase coherence. In all these cases, phase coherence can be understood in terms of phase coupling between the respective oscillatory bands. This is the topic of the next section.

5.2.2. ROM: Temporal Representational Content of the Specious Present

In presenting ROM as a theory of immanent temporal consciousness – essentially as a mechanistic account of consciousness *simpliciter* – there are four key explananda: (i) continuity and (ii) discreteness *within* a specious present and (iii) continuity and (iv) discreteness *between* specious presents. As just explained, the view here advocated is that momentary conscious experience (i.e., the specious present) depends on ROM dynamics. Moreover, oscillatory PAC multiplexing is a function of nested phase relationships. There is in fact a great deal of evidence that phase relationships – observable in various kinds of empirically measured phase couplings – are critical for realizing myriad features of conscious awareness (e.g., Achuthan and Canavier, 2009; Busch et al., 2009; Low and Strauss, 2009; Kayser, 2012; Wyart and Sergent, 2009; Fell and Axmacher, 2011; Neuling et al., 2012; Wutz et al., 2014b; Gruber et al., 2014; Kosem et al., 2014; Canavier, 2015; Maris et al., 2016; Voloh and Womelsdorf, 2016; Ronconi and Melcher, 2017).

The key idea I want to explore is whether the features of the specious present – of basic conscious experience – might be explained by different types of phase modulation among the multiple frequency bands of active reentrant oscillatory circuits.

Before turning to those tasks, it is important to point out not only the difficulty of the questions in this section – most neurobiological theories of consciousness do not go into the implementation-level weeds to such a degree – but the inherently speculative nature of the task given the current state of neuroscience. My hope is that these reflections might end up inspiring more detailed empirical work by others, on the one hand, and hitting upon something conceptually useful, on the other.

It is essential for the skeptical reader to remember, however, that the novel ideas presented in this chapter are independent of the main argumentative aims of this dissertation. The presentation of a neuroscientifically-supported extensionalist model of AM to vindicate the plausibility of extensionalist theories of the specious present is the overarching aim, and that achievement does not stand or fall with the reflections of this section. However, the ideas were so interesting to me that they seemed like thoughts worth sharing. With that in mind, I'll discuss how phase relationships in ROM networks might be helpful in explaining some of the puzzling features of consciousness.

To account for the (i) continuity within a specious present, it is natural for the ROM theorist to posit that this might be achieved by the continuity of phase coupling to slower neuro-oscillatory frequencies. Fiebelkorn et al. (2013) note that not only is phase of low delta oscillations significantly linked to visual perception *simpliciter*, but they also state "the phase of lower-frequency oscillations seems to act like a switch, controlling whether higher-frequency oscillations exert their influence…" (p. 135). This quote underscores the point made above by Buzsaki that if the phase of slower oscillations synchronizes higher frequency activity (often correlated with sensory/perceptual processing), then slight modifications of low-frequency oscillations can have large effects on gating high frequency oscillatory dynamics (either towards coherence or towards de-coherence). This is very significant, since any content carried on higher frequencies (most obviously, the basic sensory content carried by multiplexed gamma oscillations (Brunet and Fries, 2019)) can potentially be destroyed by phase resets/modulations at lower frequencies. This view is consonant with Wutz et al.'s (2014b) claim,

> Exact phase coding around transient onset may therefore provide a precise temporal integration window within which structuring and individuation of the sensory image [i.e., representational content] relies on this inhibitory timing to accurately encode visual [i.e., representational] information (2014b; p. 1563).

Two interesting further ideas come to mind. First, the relatively long oscillatory period (the duration of an oscillatory cycle) of slower frequencies might explain the extended subjective duration and non-punctate representational content of the specious present, and certainly fits with the extensionalist picture. An average oscillatory period of high gamma oscillations might be roughly 10ms, "typical" gamma oscillations being around 25ms, and average high beta oscillations having a period around 30-35ms – these are some of what I've called high-frequency oscillations. Low beta, by contrast, has an average period of, say, 50ms, while alpha oscillatory periods roughly fall between 80-120ms – these are what I called mid-frequency oscillations. Theta oscillations are an interesting case, with average periods ranging from roughly 125-200ms – they can constitute either mid- or low-frequency oscillations, depending on oscillatory specifics (this, among other things – like assuming a set oscillatory frequency applies across subjects or even within subjects uniformly – shows our oscillatory labeling is ultimately too coarse). Finally there are the low frequency oscillations: comprised of low-theta, delta ranging widely over 250-1000ms, and "superslow" oscillations that are longer than a second in length.

For the R-theorist, the ideal case to explore is whether the subjective duration and representational breadth of the specious present is plausibly explained by the objective duration and vehicular extent of oscillatory periods. Since most specious present theorists consider the specious present to have a representational content spanning ~250-750ms (Grush, Dainton and their respective followers), the R-theorist should be attracted, prima facie, to a theory that tries to get mileage out of low-frequency oscillations (especially delta). The suggestion here is to take this resemblance, this isomorphism, seriously. Importantly, there is a lot of empirical evidence supporting the dependence of conscious states on slow oscillations multiplexing with faster oscillations (Lakatos et al., 2008; Doesburg et al., 2009; Schroeder and Lakatos, 2009; Fiebelkorn, 2013; Lisman and Jensen, 2013; Harmony, 2013; Calderone et al., 2014; Arnal et al., 2015; Sachdev et al., 2015; VanRullen, 2016; Heusser et al., 2016; Tomassini et al., 2017; Chamadia, 2019). Simply put, for the R-theorist, the duration and extended nature of slow oscillations is an apt vehicular ground for explaining the duration and extended nature of the specious present. If delta oscillations ground the generation of the specious present, we have immediate explanations for the duration of the specious present, as well as why they would be variable in their duration.

Given that slower frequency bands can serve to organize and structure the activity of more local, faster frequency bands (Buzsaki, 2006; Doesburg et al., 2009; Lisman and

Jensen, 2013; Fiebelkorn et al., 2013; Voytek and Knight, 2015; Watrous et al., 2015), the stability of slower frequency bands helps explain both representational and phenomenological continuity within a specious present (Mai et al., 2019). The idea here is that a given oscillation functions in an intrinsically continuous (i.e., the phase changes continuously), non-punctate and intervallic (i.e., the oscillatory period cannot be reduced in any meaningful sense to an instant) way. If the specious present is fundamentally realized by activity organized by the period of slow-frequency oscillations, then the continuity of the content realized within the period of a given oscillation could be automatically explained, for the R-theorist, by vehicle-content resemblance. Needless to say, this would be a huge explanatory boon.

The foregoing points suggest how the extension and continuity of slower frequencies can plausibly account for the temporal extension and continuity within a specious present, but also may account for subjective duration and the representational breadth of represented temporal content.

But what about (ii) representational discontinuity within the specious present? In seeing the shooting star, we represent it at different locations during the subjectively unified perception of its flight. How is this mechanically achieved, and how can the experience of succession be explained within a unified conscious perception? The ROM theorist can posit that this occurs due to changes in phase coupling between mid- and high-frequency (which are more likely to carry sensorimotor signals) oscillatory parameters while they respectively maintain phase coupling with the slower frequency (which is more likely to relate to frontal and subcortical sources). Specifically, if mid- and higher-frequency bands alter their dyadic phase relations but remain phase coupled with sustained slower frequencies, then the phase coherence to slower frequencies can explain why the events are experienced as unified, while the phase de-coherence between mid- and higher-frequencies can explain how representational change is accommodated (within a unified specious present experience). This requires a bit of explanation. How can mid- and high-frequency oscillations become mutually uncoupled while both remaining coupled to the same peaks in the slower-frequency oscillation?

A potential answer begins with the insight that the extent of an oscillatory peak or trough is proportional to the oscillatory period. Slower oscillations, with longer wavelengths, have longer peaks and troughs than mid- and high-frequency counterparts, simply as a result of the mathematics involved (see figure 7). Because slow oscillations have longer peaks, mid- and higher-frequency oscillations can couple to the same peak in a non-overlapping manner. Mid- and higher-frequency oscillations can also couple to the same peak in an overlapping manner, but, the case under discussion, representational discontinuity within a specious present, could perhaps be accounted for by non-overlapping coupling of the mid- and high-frequencies to the same slow oscillation. The simple idea is that the non-overlap between sensorimotor-information-carrying oscillations generates the discontinuity among representational contents, while their mutual coupling to the same slow oscillation generates the representational continuity by which we characterize the experiential interval as a *single* specious present.

This invites the question of what (iv) differentiates specious presents? There are two possible explananda here, one corresponding to an objective property and another to a subjective one. The first explananda – answering the question "what objective property indicates distinction between specious presents?" – has, given the foregoing reflections, a straightforward accompanying suggestion: perhaps each successive low-frequency (e.g., delta) oscillation could provide a distinct frame within which more quickly vacillating mid- and higher-frequency signals might be integrated to generate a unified specious present. However, given an interval of baseline continuity of the delta rhythm, the transition between specious presents would presumably be subjectively invisible. This is an important point because it validates the introspective evidence that large swaths of conscious experience present no grounds for differentiating distinct conscious moments – i.e., subjective time usually seems to flow continuously during waking states. That is, conscious experience doesn't often admit of subjective discontinuities. In fact, some theorists even hold that it is a mistake to chop "experience" into anything shorter than the duration between unconscious states (Tye, 2003).

However, there is an important exception. Changes in internal attention are introspectively obvious, and this seems like a good place to look for an indicator for shifts in specious presents as subjectively experienced. I can illustrate what I have in mind by returning to the shooting star example. At first you are simply perceiving the shooting star (Kant's "inner sense"), but then you become aware of your perception of the shooting star (Kant's "apperception"). Here, I suggest, we have subjective grounds for distinguishing between specious presents. Notice that the transition is marked by an attentional change: becoming aware that one is perceiving a shooting star involves a shift of internal attention. It makes sense to consider whether this attentional shift is one means to subjectively demarcate the transition between some specious presents.

Critically, both internal and external shifts of attention have been experimentally correlated with phase shifts, specifically phase resetting[72] (see figure 8) (Achuthan and Canavier, 2009; Wutz et al., 2014b; Canavier, 2015; Voloh and Womelsdorf, 2016). Following the logic so far developed, specious presents could perhaps be subjectively differentiated in terms of phase resetting in the slower frequencies. Interestingly, in a review of experimental findings by Harmony (2013), shifts of inner attention are marked by shifts in the activity of delta oscillations. There, the argument was that increases in internal attention reliably correlate with increases in the oscillatory amplitude of delta oscillations. What about studies on the role of low frequency phase and attention tasks?

Herbst and Obleser (2019), examining delta oscillations in the context of pitch discrimination, found that delta phase predicted pitch discrimination. They concluded that, "temporal predictions are encoded in delta phase…" (abstract). Along these lines, Spyropoulos et al. (2018), found that the phase of a low-frequency 4 Hz oscillation (typically considered delta, but sometimes theta) determined not only the power of visual cortex gamma in a visual discrimination task, but that low-frequency oscillations predicted the attention shifts of macaque subjects. More interesting still, in human subjects given lexical decoding tasks, semantic analysis depended upon phase synchronization in the high delta/low theta range (Brunetti et al., 2013).

What might be inferred from these studies? They seem to show various ways in which conscious contents depend upon the phase and amplitude of low-frequency oscillations. But we know the low-frequency oscillations are insufficient to carry the

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[72] In this context, phase resetting means an abrupt transition in the oscillatory phase such that oscillatory continuity is broken. Essentially, phase resets "restart" the oscillatory source(s). Variable kinds of restart are possible, so a phase reset of some kind needn't place the oscillation back to a set point; rather, the key idea is that they generate significant oscillatory discontinuity. Since ROM involves the multiplexing of multiple oscillations,

sensory content, so a multiplexing picture emerges. Moreover, given the role of attention in the foregoing studies, one could also suggest that the vehicular discontinuity of phase resetting in low oscillations (delta or low theta, grounding a hierarchical ROM complex) explains the discontinuity by which some specious presents can be subjectively differentiated, and in a way that is entirely natural for the R-theorist.

Complete phase resetting[73] (Fig. 8) is an extreme form of phase modulation. Although complete phase resetting superficially increases the coherence of oscillatory phase, it actually *destroys the hierarchical multiplexing required by ROM for representational continuity*. If the continuity of slower oscillations grounds experiential continuity within specious presents, the discontinuity involved in the phase resetting/realignment of the slower frequencies provides a ready explanation for how successive specious presents are subjectively differentiated. In this way, *phase resetting in the slower frequency bands might naturally mark – inner attention defined – introspectable boundaries between specious presents, while the relative longevity of stable low-frequency rhythms vis-à-vis the time scales applicable to mid- and high-frequency oscillations (carrying the signals subvening sensorimotor representational content) grounds the experience of continuity between specious presents*.

[73] Phase changes among frequency bands are variously characterized as phase reset, phase modulation, phase shift or phase alignment by various researchers (Spaak et al., 2014; Gruber et al., 2014; Kosem et al., 2014; Canavier, 2015); there are differences between some of these authors' conceptualizations, but none makes a difference in this discussion.

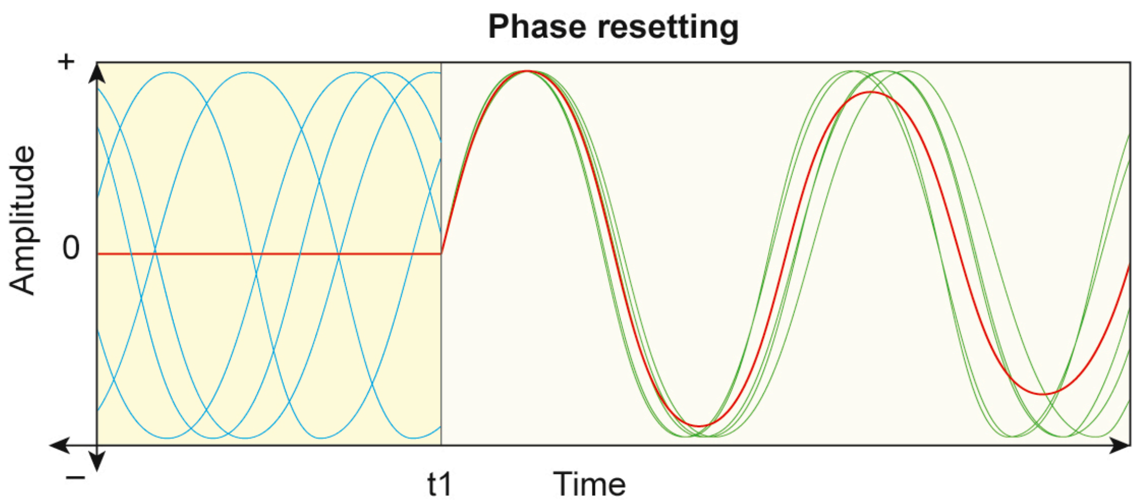

Figure 8: An idealized illustration of *complete* phase-resetting/modulation. Given the many oscillatory frequencies contributing to the cognitive and conscious economy, such complete phase-resetting would be extremely rare (cf. Buzsaki, 2006). Notice that such phase resetting destroys the complexity of preceding oscillatory dynamics. (Piper, 2019).

One of the largest unsolved problems is how successive specious presents (i.e., successive conscious frames or perceptual moments) are related such that we experience (iii) phenomenological continuity between them despite changing representational contents (VanRullen, 2016; Weise, 2017; Chuard, 2017; White, 2018). Here, there are two key ideas, I think. First, just mentioned, a relatively stable low-frequency oscillation might be able to ground the basis for continuity. The second key idea implicit in ROM dynamics is that while phase resetting is a mechanism to potentially help explain internal shifts of attention, *phase resetting is almost always only partial*. In a partial phase reset, not all the multiplexing of hierarchical (slow-, mid- and high-frequency) and spatially distributed neural signals is destroyed. And the multiplexing (i.e., phase coupling) between oscillatory components that does remain can potentially account for whatever representational and phenomenological continuities persist from one specious present to another and within them (cf. Ronconi et al., 2017). Some basic questions immediately arise: (1) what is the mechanism of partial phase reset, and (2) what is the relationship between partial phase reset and representational continuity?

(1) Partial phase reset is possible exactly because the ROM machinery implicates phase coupling within an oscillatory *hierarchy*. This means that some coupled oscillations can de-cohere while others are sustained and yet others are created de novo. As long as phase coupling persists between some levels of the hierarchy at every time point through an interval, a vehicular basis for representational continuity through that interval exists. Of course, exactly how much coupling is required is an open question, but the basic idea is plausible.

(2) The postulated relationship between partial phase reset and representational continuity is straightforward: phase coupling to the slower oscillations generates more extended types of continuity, while phase coupling to the higher frequencies generates more transient types of continuity. More specifically, phase coupling to slow oscillations might undergird representational continuity between specious presents as well as the sustained representation of unchanging objects/properties within a specious present, while phase coupling to higher-frequency oscillations accounts for representational trajectory continuity of changing objects/properties within a specious present. As mentioned, this nicely dovetails with a great deal of neuroscientific evidence that slower oscillations correspond to the operation of attention, memory and executive processes,

while faster oscillations correspond to sensorimotor processes (Voytek and Knight, 2015).

Critically, save for cases of going unconscious by trauma or sleep, phase modulation among multiplexed oscillatory components is always partial: not all multiplexed oscillatory components de-cohere together (Buzsaki, 2006; Rangel et al., 2015; Canavier et al., 2015). Consider the orchestra analogy again: even if each player plays independently, there will always be various transient coherences among the players' rhythms, pitches, etc. simply by matter of coincidence. And when there is more complex coherence, as under the guidance of a conductor performing a composer's work, or a brain organized around a task or interactive process, the coupling within the oscillatory hierarchy can achieve very high dimensionality. A very plausible theoretical suggestion is that the complexity of representational content is proportional to the complexity of the oscillatory hierarchy realized (cf. Edelman and Tononi, 2000; Piper, 2012), though this won't be defended here.

Summarizing the foregoing, the claim of the ROM theorist, as I have developed it, is that the sustainability of *some* forms of *coherence*, due to the persistence of some degree of phase-coordinated PAC multiplexing, explains (iii) the continuity and flow of temporal representational content between and within specious presents. I suggest that it is a great merit of this oscillatory framework that it provides an explanation for both the discreteness and continuity within *and* between specious presents via *one mechanism*: the degree, and type, of phase resetting between ROM components determines the degree, and type, of discreteness between specious presents, while the phenomenology of continuity derives from the neuro-vehicular continuity of sustained forms of coherent multiplexing. The foregoing ideas are summarized in Figure 9.

SPECIOUS PRESENT PROPERTY	ROM VEHICULAR DYNAMICS
1. Continuous representational or phenomenological content within a specious present	1. Generated by sustained phase-coherence of higher and/or mid-frequencies to the slower frequencies grounding a reentrant multiplexed network.
2. Discrete representational or phenomenological content within a specious present	2. Generated by phase de-coherence of higher and/or mid-frequencies to the slower frequencies grounding a reentrant multiplexed network.
3. Representational or phenomenological continuity between specious presents	3. Generated by sustained phase-coherence of higher and/or mid-level frequencies during a phase-reset of the slower frequencies grounding a reentrant multiplexed network.
4. Representational or phenomenological discreteness between specious presents	4. Generated by phase de-coherence of higher and/or mid-level frequencies during a phase-reset of the slower frequencies grounding a reentrant multiplexed network.

Figure 9: A summary of the ROM account of Specious Present features.

The speculations regarding the key role of phase relationships does not take place in a mechanistic vacuum of course. All of the abovementioned dynamics only correspond to conscious contents, on the view under consideration, when instantiating reentrant circuitry involving the thalamus and brainstem systems (Newman and Baars, 1993). But the role of reentrant circuits is obviously a significant one, for it is in specifying the neural regions comprising the reentrant circuits that we can understand what kind of representational contents are conscious (in addition to the temporal content intrinsically generated, as illustrated in the AM model, and discussed at more length in the next section and final chapter).

So a further thought is that in addition to the continuity brought about by the rhythmicity of low-frequency multiplexes, the role of sustainably depolarized reentrant circuits must be highlighted. When skilled focused sensorimotor activity is required on short-time scales (sports, translation, musicianship, etc.), the sensorimotor relevant regions presumably enter into sustained reentrance, since successful action sensitively depends upon the integration of various stimuli and motor programs, among other regions. The point is a general one, but the upshot is interesting.

In previous chapters, Dainton's idea of numerical identity was discussed. In the sustainability of reentrant circuits over time frames eclipsing that required for sensorimotor processing, the temporal sustain of reentrant circuits provides a mechanistic explanation for how that continuity would be realized. In this way, ROM appears as a neurobiological instantiation of an overlap extensionalist theory (without delay, though). The broader idea is this: the shifting coalitions of reentrant circuits might help explain the shifting representational content of the specious present, while the relatively conserved activation of some reentrant circuits, due to particularly strong depolarization, amidst general network change might help explain why the just-mentioned changing representational contents can be integrated into the experience of the unity and continuous subjective flow of conscious experience.

In closing this section, I have advanced some speculative ideas about how ROM mechanisms might account for the nuances of shifting and sustained temporal representational content. As mentioned, the success of this dissertation does not rest on the fate of these speculations, but it is hopefully enhanced by its inclusion. In the next section, I turn to an explanation of the philosophical implications of the ROM model, with the emphasis on how ROM instantiates an extensionalist theory, and the ways in which it does.

5.3. ROM: Philosophical Characterization of the Specious Present

> *The concrete pulses of experience…run into each other and seem to interpenetrate… You feel no one of them as inwardly simple, and yet no two as wholly without confluence where they touch. There is no datum so small as not to show this mystery, if mystery it be. The tiniest feeling that we can possibly have comes with an earlier and a later part and with a sense of their continuous precession. (James, 1909; p. 282).*

In this section, I want to briefly spell out some of ROM's philosophical commitments and affiliations. I'll begin by reviewing what kind of representational content I take ROM's theory of the specious present to account for. I then discuss the nature of ROM's extensionalist commitments. I turn to consider the relation of ROM to neurobiological theories of consciousness, before examining its relation to the representationalist vs. anti-representationalist debate more broadly. ROM makes philosophical contact with other theories; however, I wait until chapter 7 to discuss those more speculative connections.

5.3.1. The Representational Content of ROM's Theory of the Specious Present

I take the proprietary representational content of immanent temporal consciousness – the specious present – to have the following characteristics: it is non-conceptual, narrow, B-ish, and of chaotic spatiotemporal extent.

As a theory of the specious present, I take ROM to provide theory of narrow temporal representational content. The idea, in this context, is that temporal representational content in the specious present can, but need not, reflect the timing of external events. We obviously need to represent rates of external change in our temporal representation to successfully act in the world, but the temporal representational content doesn't depend on the environment for the nature of its content; that is, the environment doesn't determine temporal representational content. It merely has accuracy conditions that correspond to the environment. The independence of temporal representational content from external referents is commonly exemplified in trauma states of various kinds, drug-induced hallucinations and dreams; in all these cases, the experience of time can be indistinguishable from normal waking consciousness but is obviously independent of external referents/sources.

How does this dovetail with ROM? The circuits implicated by ROM theory are location non-specific, cortically speaking. A full model will require thalamocortical circuitry, but it isn't obvious that simple kinds of representation require frontal or executive centers. Presumably, conceptual content requires not just perceptual processing, but categorization of some kind over perceptual content. A simple kind of perceptual organization might be found in the pre-motor and motor cortices, in the way that they might organize distinct perceptual contents by the common denominator they afford for action/interaction ("affordances"), but motor cortices are not necessary for basic kinds of perception. So it seems likely that the cortical non-specificity of ROM allows for non-conceptual representation.

The more important point, however, is how temporal representation is generated on the ROM picture. Temporal representation is an intrinsic product of the temporal dynamics of the ROM machinery. As an intrinsic product, it is orthogonal to processing other signals. It provides the framework for organizing signals, but not by (conceptually) categorizing them; rather serving to temporally structure them. Hence, the ROM model comfortably explains the non-conceptual nature of the temporal representation content of the specious present.

These points also help explain why ROM is suited to explain why the specious present should be characterized by "narrow" content. ROM shows how internal processes, independent of external factors, generate temporality on their own; ROM circuits generate temporal representational content intrinsically. The idea can be unpacked in terms of molecular duplicates; regardless of environmental differences, molecular duplicates will experience the same temporal representational content in the specious present, even if there are vast differences in other types of representational content (the molecular constitution of objects characterized by appearances, e.g.). In chapter 7, I will discuss the consonance of ROM theory with state-dependent networks and population clocks; these latter models are particularly interesting in the context of the current point because they, too, generate temporal properties intrinsically, in the process of processing a-temporal properties.

ROM is apt for characterization as producing B-ish content because the concepts of past and future simply aren't applicable. What the ROM model tries to show is how our experience of a moving "now" is neurobiologically realized. All the representational content of the specious present is experienced *as* the present. As a result, the concepts of earlier-than, simultaneous and later-than are apposite, while the concepts of past and future are not.

Turning to my last point in this section, considering the spatiotemporal extent of specious presents and thus basic conscious experiences, I begin with the basic observation that if the above speculations are correct, and the extent of the specious present is determined by the frequency of the slow oscillations to which mid- and higher-frequency oscillations are phase coupled – and the extent of reentrant circuit activation – then the variable duration of slow oscillations implies that specious presents themselves are *always* generated with variable durations/extents, which implies that specious presents aren't restricted to a singular set metric "size" (cf. Ronconi et al., 2017). This is a very intuitive idea and one supported by the common introspection that not all conscious "moments" are experientially equivalent: some are protracted and imbued with profound subjective significance while other moments are subjectively diaphanous and unremarkable.

White (2018) independently reaches this conclusion: "it is clear from the research evidence that, not only is there no support for the occurrence of discrete frames, even local ones, of fixed duration, but such frames would be functionally inadequate, lacking the flexibility to deal with variations in stimulus conditions"[74] (p. 118). See also Crick

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[74] White (2018) is arguing against two claims, both of which are at odds with ROM. One, he argues against the idea that there are discrete frames, where discrete is taken in a strong sense to imply that consciousness

and Koch (2003) for further agreement on the variable duration of conscious frames/moments.

This is extremely useful, since it offers an account that squares with both the experimental variability in time research and, more interestingly, various distortions in immediate temporal consciousness, even those characterizing certain hallucinogenic states (e.g., those caused by LSD, DMT, etc.). In general, however, specious presents will be roughly of similar duration in virtue of similar circuits being activated, and this accounts for the generic consistency of experience and experiment. Note that, given the profoundly complex and chaotic nature of neurodynamical activity during waking states, particular components of ROM are easily disrupted and hence short-lived (Buzsaki, 2006). This is evidenced by the EEG "desynchronization" characterizing waking vis-à-vis slow-wave sleep states, and explains why the specious present – the experience of the momentary "now" – is also brief and transient.[75] Buzsaki (2006) explains:

> A critical aspect of brain oscillators is that the mean frequencies of neighboring oscillatory families are not integers of each other. Thus, adjacent bands cannot simply lock-step because a prerequisite for stable temporal locking is phase synchronization. Instead the 2.17 ratio between adjacent oscillators can give rise only to transient or metastable dynamics, a state of perpetual fluctuation between unstable and transient phase synchrony… (p. 120)

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is comprised of functionally and representationally atomic parts (as opposed to molecular or "non-atomic" views, as opposed to the view that conscious experience is continuous). Two, he argues against is the idea that discrete frames (even if such there be) are restricted to a set size/duration. ROM rejects both these views and hence White's analysis is indirectly supportive of some ROM commitments.

[75] Rick Grush asks if it were possible to reduce the chaos of waking states, would ROM predict that specious presents with much more extended representational content could be realized? I suggest yes. Evidence that this is plausible comes from various distortions of temporal consciousness (including those induced by some trauma, drugs and meditative practices), which show that there are various ways to distort specious present representational content. ROM explains these distortions as a result of extending/reducing the duration of the oscillatory resonances realizing temporal experience extending/reducing the duration (amount) of content represented within the specious present. This is a happy result, because it shows how the ROM framework can be very naturally extended to account for deviant cases.

5.3.2. ROM's Extensionalist Commitments

I have claimed that ROM provides a neuroscientifically supported R-theory extensionalism of the specious present. Now, extensionalism might be taken to mean various things, including

(a) that experienced temporal extension resembles the temporal extension of relevant brain processes ("extension mirroring"),

(b) that experienced ordinality resembles the ordinality of relevant brain processes ("ordinal mirroring"),

(c) that experienced continuity resembles the continuity of relevant brain processes ("continuity mirroring"), or

(d) that experienced duration resembles the duration of relevant brain process ("duration mirroring").

Here, I will argue that ROM satisfies (a) through (d). From chapter 4, it was shown how AM was explained by extended "online" dynamics. The multiplexing required to generate conscious contents only integrates the ingredients for temporal extension by being isomorphically temporally extended. The machinery generates temporally extended representational content only in virtue of a temporally extended integrative mechanism. Hence, ROM satisfies extension mirroring.

Chapter 4 also provides the main argument for ordinal mirroring. There it was illustrated how the ordinality experienced is an exact product of the ordinality with which representational content is integrated in the ROM circuit. The explanation for experience order just is the order of ROM dynamics. So it is clear that ROM honors ordinal mirroring.

Next, the argument for why ROM supports continuity mirroring is that the oscillatory multiplexing necessary for consciousness realizes a continual electrodynamical manifold, on account of partial phase reset allowing for the preservation of some forms of phase coupling, enough to maintain a hierarchical oscillatory system. Since it is the continuity of the hierarchically nested vehicular processes that realizes continuous representational content, continuity mirroring is satisfied. Chapter 6 will contain greater elaboration and argument on these matters as well as address objections to these claims.

What about duration mirroring? Does the objective duration of re-entrant oscillatory multiplexing isomorphically determine the subjective duration of experience? Let me start by making the point that persistence of vision tells us experience does not correlate with external events, so I will not be interested in the relation of duration between external stimuli and internal experience. But what if a 10ms flash causes 100ms of ROM, which realizes 100ms of temporal representational content? In this case, duration mirroring would obtain via ROM dynamics.

Looking at the ROM model of AM in Chapter 4, it is clearly illustrated how the model instantiates duration mirroring. It explains the duration of an experience by an isomorphic duration of ROM – independent empirical and theoretical support was also given for the durations produced by the model. Other independent reflections suggest duration mirroring is true.

It is not a contested claim amongst neuroscientists and most philosophers of mind that conscious experience depends on neuroelectrodynamics. So it would be natural to assume that conscious experiences would last only as long as the relevant neuroelectrodynamics. ROM is a theory of the relevant electroneurodynamics supporting consciousness during the specious present. Now we know that neural firing rates correspond to the length of subjective duration (Periyadath and Eagleman, 2008; 2012). The evidence shows that neural firing rate suppression corresponds to duration contraction, while neural firing rate enhancement corresponds to duration extension. But we also know that individual neuron firing operates by a series of fixed time constant influences – these are the inspiration for the spectral models discussed above. So, ceteris paribus, high firing rates correspond to longer depolarization while shorter firing rates correspond to shorter depolarization. Thus, we get the general inference that long subjective durations correspond to longer depolarization events, and vice versa. Simplifying, we get the result that the length of relevant neural activity proportionately predicts the experience duration.

Hence, the neuroscience actually supports the idea that a duration mirroring constraint is not only possible, but likely. What is needed is a theory of what kinds of neural firing activities are relevant for explaining consciously experienced time.

Of course this is where ROM comes in. It plausibly harmonizes the neuroscience on time consciousness of the specious present with duration mirroring, along with the other kinds of temporal mirroring already discussed. If true, this would be an extremely happy theoretical result. It would tidy up the relation of the philosophy and neuroscience of time and establish new experimental paradigms to explain the specious present through objective measures.

5.3.3. The Relation of ROM to Neurobiological Theories of Consciousness

As discussed, ROM is a model of how temporal representational content is an intrinsic property of ROM circuits. I will return to this point when comparing ROM with timing models (ch. 7). Hence, time is not an add-on representational property. *On ROM, time consciousness is generated intrinsically, of necessity, in the realization of conscious states*. This explains why there are no atemporal conscious states – why all conscious experiences include a sense of temporal passage, of immediate temporal consciousness. In that way it is in line with the work of many philosophers who, in various ways, argued that time is a special property vis-à-vis consciousness (e.g., Kant, Husserl, James, Stern, etc.). Now how does ROM theory relate to extant neurobiological theories of consciousness?

Wu (2018) distinguishes 4 main types of neurobiological theories of consciousness: global neuronal workspace, reentrant theories, higher-order theories, and information integration theory. After briefly characterizing them, I will explain how ROM sits in relation. Foreshadowing, however: as developed in this manuscript, ROM marries a local reentrant theory with aspects of the information integration theory. Most interestingly, ROM intrinsically includes a neurodynamical model of the global neuronal workspace theories – it just isn't included in the model presented in chapter 4. More on all this below.

The first view canvased is the global neuronal workspace theory (Baars, 1988; Dehaene et al., 2006), which holds that neural activity realizes a conscious state when and only when it is part of the global neuronal workspace and thus becomes accessible to other encapsulated systems, like memory, affective, perceptual, attentional and motor systems. In order for a local/encapsulated neural population to contribute to the global workspace, it must form a reentrant circuit with the dynamically changing global workspace; once this has occurred, the information processed in the local neural population is accessible to the global workspace and can be accessed by other local neural populations and systems. It is the global broadcast of information to multiple subsystems that accounts for conscious contents. The argument is that since conscious contents are available to guide reason and behavior, some kind of global broadcasting (of a global workspace) must be required.

The second view, the reentrant theory, is similar in positing reentrant connections as key to the generation of conscious states, but it does not require global broadcasting (Lamme, 2003; 2006). Instead, this view holds that conscious states can and do arise in local circuits, e.g., sensory circuits, even if a more global neural network is required as part of the implementation conditions. Lee (2014) usefully distinguishes between "core" and "total" realizers. On the reentrant model, local sensory circuits are the core realizers, while much larger neural networks (probably not the whole brain, but a significantly larger portion than sensory networks) correspond to the total realizer. Similar to the AM model outlined in chapter 4, which accounts for visual consciousness by reference only to local sensory circuits, but doesn't ignore the need for contextualization within larger brain networks, the reentrant theory posits that such conditions are necessary and sufficient for the generation of conscious states. (It is important to restate the caveat about the AM model being streamlined for illustration purposes. It is not committed to the view that larger networks – especially parietal association cortices (often reciprocally connected with frontal attentional networks) – aren't required for AM experiences.)

The third view, the higher-order theory, posits that when a first-order state is represented by a higher-order state the first-order state becomes conscious (Rosenthal, 2002). The loci of these higher-order states are prefrontal circuits. There is a fair amount of ambiguity in operationalizing higher-order theories, since the requirements for the representation relation are unspecified. Notice that if higher-order representation requires the establishment of recurrent connections involving association cortex hubs, higher-order theories start to look a lot like a species of the global workspace view.

Lastly, the Information Integration Theory (IIT) holds that a system is conscious if the informational content of the whole system is greater than the sum of informational content of its parts (Tononi, 2008). More technically, "if there is no partitioning [of the system] where the summed informational content of the parts equals the whole, then the system as a whole carries integrated information and….is conscious" (Wu, 2018). The biggest concern about IIT is that there are many systems with integrated information (the internet, e.g.) that no one considers conscious. Although further constraints will need to be added to IIT to make it truly useful, it has generally been taken to be an interesting starting point for theoretical speculation.

ROM theory is congenially situated with respect to the foregoing theories and could be adopted as a neurobiological framework by any of them. It sits most naturally with the global workspace and reentrant theories on account of its focus on reentrant circuits. Since the size of the ROM network can vary, ROM can be employed by either theory very naturally. The AM model in chapter 4 essentially instantiates a reentrant theory of consciousness, but if frontal association cortex hubs are included in a model it will arguably instantiate a global workspace model. Additionally, ROM provides a possible mechanism to explain how higher-order and information integration theories might be implemented. ROM's reentrant circuitry gives insight into how higher-order areas might represent lower-order areas, while multiplexing seems a good candidate for a mechanism by which information integration could occur.

Returning to a point just made: in the AM model presented in chapter 4, the focus was upon local circuits in the visual cortex. As explained, this was for reasons of explanatory efficiency, rather than theoretical necessity. As discussed in chapter 5, the full ROM model instantiates a mechanism of phase coherence between low-, mid- and high-frequency oscillations. This brings us to an empirical question. If local circuits can instantiate the hierarchical ROM mechanism, then local circuits can support consciousness and the reentrant theory is correct. However, if the requirement to multiplex to low-frequency oscillations implies the kind of large-scale activity characteristic of global workspace theories, then this latter theory would, on ROM, be correct.

There is room for debate here. While a slow cortical potential at delta frequency can be generated in the superficial layers of sensory cortex (He et al., 2009), many generators of delta rhythms are subcortical or prefrontal (Headley and Pare, 2017; Helfrich et al., 2017). These considerations pull in opposite directions, but also appear to provide the grounds for showing how ROM may harmonize the global and local consciousness views. What we might say is that while global broadcasting is not required for conscious experiences of a simple sensory nature, it is required for more complex conscious experiences, including those that can be introspected or reported upon. And that seems like a realistic and thus happy conclusion.

5.3.4. ROM and the Representationalist vs. Anti-Representationalist Debate

A natural question to ask is how the ROM theory of the specious present intersects with representationalist vs. anti-representationalist debates in philosophy of mind. On the one hand, the ROM model intrinsically generates the temporal representational content of the specious present in the manner of state dependent computations (Paton and Buonomano, 2018 – see chapter 7). Interestingly, as we saw in chapter 4, it does this by processing modality-specific stimuli, creating temporal representational narrow content in the process. Gerardo Viera (2016), citing Buonomano's work, independently argues for a similar claim: "temporal representations involve distinct uses of the underlying machinery used in spatial representation" (p. 30). According to these reflections, ROM theory is a narrow representationalist theory of temporal content.

However, other reflections pull towards anti-representationalism. In the first place, ROM theory shows specious present experience is generated intrinsically and without separate computational vehicles for temporal contents, a position very much in line with dynamic systems thinking. Secondly, ROM is a model of how specious present features might be generated locally, dispensing with the need for a central representation or dedicated timing mechanism (see ch. 7 for more on this). Thirdly, even when time is used by the organism for the guidance of action during the specious present, it is not amodal; rather, it is a product of modality-specific stimulus processing. Finally, ROM endorses the enactivist/embodied views that the nature of peripheral receptors makes a critical difference in experience, temporal or otherwise, since the body and interaction with the environment provide the raw materials that form ROM circuits/networks. In all these ways, ROM seems to endorse an anti-representationalist theory of the specious present.

What I suggest is that the representationalist vs. anti-representationalist debate amounts to a false dichotomy in many cases because of ambiguity over representational vehicles. Only by getting clearer on the neurodynamical realizers of representational content can we say if, e.g., a nominally "anti-representationalist" view is actually at odds with a representationalist picture. Wilson and Foglia (2015) make a similar point: "It is unclear why embodied cognitive science could not also be symbolic, representational, abstract, etc. Puzzlement here is magnified by the fact that many self-styled embodied approaches are symbolic, representational, abstract, etc…"[76]

Were I to put the temporal properties generated by ROM into the foregoing debate, I would suggest the following. The sense of time generated in the specious present is representationalist in being best described as narrow content generated intrinsically via modality-specific stimulus processing. While the use of time for action guidance in the specious present is anti-representationalist in the sense of being modality-

[76] The quote continues: "One view that adapts, rather than dispenses with, the notion of mental representation is Lawrence Barsalou's perceptual symbols theory [which]…rests on the assumption that human cognition does not consist of amodal representations that bear arbitrary relations to their referents in the world, but rather representations whose activation patterns include information from various sensory modalities…" (Wilson and Foglia, 2015).

specific, enactive, embodied and the dynamic product of organism-environment interaction.

Why should temporal perception be so special vis-à-vis other experiential properties? In addition to Phillips (2014) observation that temporal properties are uniquely applicable to experiences themselves, Viera (2016) provides another insight:

> The particular difficulty, however, is that time is unlike many of the other aspects of our world that the perceptual system is capable of tracking and representing. Specifically, it's the odd way in which time can (or cannot) causally influence the operation of the perceptual system. Time, or temporal properties of events, are not capable of causally influencing the operation of the perceptual system in the same way that something like the surface reflectance of objects can. For these reasons a simple causal theory of content seems to make it difficult to understand how perception could represent time. (p. 196-7).

Given the uniqueness of temporal perception within the ambit of experiential properties, it is therefore unsurprising to have required a novel theory of representational vehicular structure and a hybrid theory of representation.

5.4. ROM-Theory Summary

Call a view having the following components the ROM-theory of the specious present.[77]

A. First-order vehicular structure: oscillatory framework (Varela et al., 1991; Fries, 2005; Buzsaki, 2006).

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[77] There is a further question of how far a ROM theory of time consciousness can be taken. It is plausible that the basic mechanics can be useful in explaining part or all of types of temporal consciousness distinct from the perceptually-defined specious present. The arguments of this dissertation do not depend on such possibilities, but I will say more on this later, as it inflates the potential importance of the theory.

B. Second-order vehicular structure: oscillations multiplexed through PAC (Canolty and Knight, 2010; Jirsa and Muller, 2013; Voytek and Knight, 2015).
C. Third-order vehicular structure: reentrant circuits carrying multiplexed oscillations (Edelman, 1992; Lamme et al., 2003; Arstila, 2016).
D. Meta-vehicular structure: hierarchically nested overlap (Pettonen and Buzsaki, 2003; Voytek and Knight, 2015).
E. Neurodynamical model: differential latency (Baldo and Caticha, 2005).
F. Temporal individuation structure: interval (Phillips, 2014).
G. Specious present structure: Extensionalism (Rashbrook-Oliver, 2016).

In the earlier sections of this chapter, the nature of commitments (A)-(C) and (G) were described in some detail above. I shall say more about (D)-(F) here.

The idea behind (D) falls directly out of the nature of ROM. As mentioned, temporal representation on this view depends upon the multidimensional coherence of multiple oscillatory parameters over time. Given differences in these oscillatory parameters, they do not change or co-vary uniformly. For example, higher frequency oscillations can be embedded within the temporal confines of slower oscillations. In this way, faster oscillations will be nested within slower ones. This nesting can occur over more than four orders of magnitude, ranging from ultra fast oscillations up to 600 Hz to ultra slow oscillations occurring over dozens of seconds (Penttonen and Buzsaki, 2003). Thus, the oscillatory system of the brain is both hierarchical and naturally nested in a fractal-like manner. As mentioned, slower oscillations provide a way for faster oscillations to be coherently organized into functional subpopulations. Since this kind of process can occur over many orders of magnitude, a truly complex neurodynamical functional system is realized. A consequence of this hierarchical nesting is that vehicular structure is partially conserved during representational changes. Because successive representational contents typically share some vehicular structure, the overlap of realizers provides a nice explanation for representational and phenomenological continuity. ROM enshrines and illustrates this principle, which will be critical for explaining why ROM doesn't imply an anti-extensionalist theory – an objection answered in Chapter 6.

The idea behind (E) was introduced in chapter 1. Differential latency views explain mismatches between stimulus order and represented order due to differences in the latencies involved in sufficiently processing such stimuli (Ogmen et al., 2003; Baldo and Caticha, 2005). Experiments have shown that latencies are affected by all kinds of factors, including stimulus intensity, inter-stimulus intervals and task conditions (ibid.). The ROM model incorporates these experimental findings very naturally since it posits multiple mechanisms – reentrant circuits and variable oscillatory processing windows – that instantiate stimulus- and task-dependent differential latencies. The basic idea of these models is simple: the order of the latencies determines the order represented. ROM's AM model, introduced next chapter, shows this in action.

To explain (F), first consider that atomist and cinematic views prioritize temporal instants over temporal intervals. This is the commonsense approach enshrined in physics and science generally. If you want to understand what occurred during an interval, you add up the events occurring at each instant within that interval. Understandably, many researchers studying time consciousness have adopted this basic idea. Although it makes perfect sense when discussing objective time and when studying objective events, extensionalists have argued it doesn't quite make sense when trying to understand the (subjective) specious present. Instead, extensionalists have argued that the temporal representation occurring at a given instant is parasitic upon an embedding interval (Phillips, 2014). By my lights, there are 3 key explanations for this reversal.

First, and most simply, temporal representation is a process that itself takes time. Thus, there is a clear sense in which what is represented, temporally or otherwise, depends upon a processing interval. The other two explanations flesh this out. Second, as the differential latency model just discussed makes clear, temporal representation itself takes time and the represented order of events depends not only on the order of stimulus presentation but also on the nature of, and relationship between, stimuli. Because how a stimulus X is processed can change depending upon the neurodynamics preceding and slightly post-dating the initial registration of X, even though we can refer to the representation of X (X') as occurring within experience at a moment characterized as an "instant", the actual details of the process show that the experience of X' supervenes on the processing interval within which it is a part. And third, the ROM model requires reentrant circuits to generate temporal content. This supports (F) because the nature of oscillations and circuit dynamics is intervallic. Just as an electrical circuit only conducts electricity when it is closed, so too, reentrant circuits on the ROM picture operate similarly – with information flow that takes place over time. The extended durations required for active reentrant circuit information flow support an intervallic, as opposed to instantaneous, conception of temporal representation.

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<u>Chapter 6: Core Scientific and Philosophical Objections to ROM</u>

6.1. Introduction

Given its scope, the ROM theory of temporal perception is subject to a host of objections. In broad strokes, these can be divided into scientific and philosophical varieties. Some leniency in the distinction is of course required, as objections based on scientific grounds can be motivated by, or aim towards, philosophical ends, while philosophical objections often turn on analysis of scientific data. But the distinction will be roughly helpful, I think, in organizing objections for the reader.

In general, scientific objections are those that challenge the science or data employed by the ROM model, while philosophical objections are those that challenge its large-scale theoretical claims. I'll look at objections in that order.

6.2. Neuroscientific Objections to the ROM Account

6.2.1. Overview

Four general objections should be considered. First of all, the cited circuitry may be wrong; secondly, the given latencies may be wrong; third, absence seizures seem to violate ROM's continuity thesis, and most problematically, it might be argued that the oscillation framework requires an NR view. I'll look at each in turn.

6.2.2. Does ROM Employ Inaccurate Circuitry?

Arguing that the model involves the wrong circuitry is implausible on neuroscientific grounds: extensive evidence shows that the integrity of functioning of the LGN and V1 are both required for conscious visual representation, and V5 is required for visual motion representation (cf. Arstila, 2016a). As noted, I admit that a full account of all possible AM phenomena will include network interactions with the LGN (Ronconi and Melcher, 2017), IPL (Battelli et al., 2007; VanRullen et al., 2008), M1 (Jantzen et al., 2013) and possibly theta-generating frontal regions (Sanders et al., 2014), but it is unclear that incorporating them would change the aforementioned picture of basic apparent motion, while definitely making it unwieldy for a manuscript length treatment. Reasonably, those wishing to take issue with the circuitry bear the burden of argument.

It bears repeating that the extent of the circuitry discussed is insufficient to handle many cases of AM and, a fortiori, most of the possible representational contents of the specious present. But, as mentioned, this pared down example not only includes the critical cortical pathways for AM but also is manageable enough to follow. A full model – fully compatible with ROM's basic machinery – likely requires a computer simulation/model for adequate uptake. Hence, there are good grounds for restricting the discussion to that covered.

6.2.3. Does ROM Employ Inaccurate Latencies?

A more realistic complaint is that the latencies might be inaccurate. I am sympathetic to this concern. The time frames used are drawn from minimal latency estimations, but the explanation isn't restricted to operating at these minimal durations. Accordingly, it seems likely that typical experiences unfold over longer time frames on average (adding credulity to its explanatory sufficiency). (This has been reinforced with the well-known example of persistence of vision, where the visual experience continues much longer than the objective stimulus presentation due to sustained depolarization). Although minimal, the time frames outlined here dovetail nicely with lower-bound estimates about minimal latencies for conscious visual awareness – a point Arstila himself brought to my attention (2016a). Specifically, he discusses that the visual awareness negativity (VAN) and late positivity ERP components highly correlate with conscious visual experience and have neurodynamical latencies between 200-300 ms (Koivisto and Revonsuo, 2010). Finally, the general mechanistic picture has received indirect experimental support – Romei et al. discovered that enhancing reentrant circuits from V5 to V1 increased motion sensitivity (2016).

Instead of specific millisecond latencies, latency intervals around a mean should be considered – since consistent instantaneous timing is not the nature of biological systems. Incorporating intervals into the analysis would have made the model awkwardly complicated though. Regardless, my explanatory shortcut is unlikely to be a problem. I have utilized the mean latencies supported by primate science. If they are roughly correct, then any generic deviations should balance out given the extensive homologies of primate neurophysiology. All that is required for the model to work is that the *proportions* between latencies hold. This is because I am providing an extensionalist explanation of the order of temporal contents in terms of the order of neurodynamics. If these neurodynamical estimates are unanimously lengthened or shortened, it doesn't change the relative order of circuit activations, and therefore doesn't change the predicted order of temporal representational contents.

6.2.4. Do Absence Seizures Falsify ROM's Continuity Mirroring?

Absence seizures occur mostly, but not exclusively, in children from 4-15 and some involve the temporary loss of consciousness (typically on the order of one to a few seconds, but occasionally up to 25 seconds or so) of consciousness concurrent with the appearance of low-frequency (delta) oscillations (Albuja and Murphy, 2019). So in effect, during an absence seizure the ROM dynamics – if they are maintained at all – are reduced in complexity as the mid- and high-frequency amplitudes decrease while the low-frequency oscillation amplitude increases. The domination of brain oscillations by low-frequencies presumably causes a loss of consciousness.

There are two types of absence seizures: "typical" and "atypical," and in the former, but not the latter, subjects report no memory of the seizure – while those having had atypical seizures report the experiences (Blumenfeld, 2005). These are not cleanly separable kinds of seizure, however; they lie on a spectrum (Holmes et al., 1987). So in some absence seizures, subjects report no memory for the experience, and thus plausibly experience no discontinuity. The problem then is why possible discontinuity in the ROM dynamics isn't accompanied by a resemblant report of subjective discontinuity. This appears to violate the continuity claim and amounts to a serious objection to one of ROM's theses. What then should be said in reply?

One answer would be to bite the bullet and reject the continuity thesis of ROM. This wouldn't falsify ROM entirely, but would decrease the ambit of its theoretical scope. But it isn't clear that the continuity thesis can be cleanly excised, like removing a cookie from a jar, leaving the remainder unaltered. Rather, it may be the case that giving up on the continuity claim is more like removing a rope from a bag of ropes – if they're all intertwined, you might empty the bag. So before resorting to this option, other possibilities should be considered.

In the first place, notice that the two types of absence seizure have been independently argued to form a continuum (ibid.). One of the leading researchers into the neurodynamics of absence seizures, Hal Blumenfeld, reports in his (2005) review:

> Numerous human and animal studies have suggested that absence seizures are generated through *abnormal network oscillations* involving both the cortex and thalamus….In addition, *even in typical absence seizures there is substantial variability in the degree of impaired consciousness* from one patient to another, and even from one episode to the next in the same patient (p. 273; my italics).

Moreover,

> Several converging lines of evidence suggest that *impaired consciousness during absence seizures is not a global phenomenon, but rather can be decomposed into specific deficits in a number of different cognitive functions,* associated with impaired function in selective neuroanatomical networks…(p. 277; my italics).

This suggests the simple possibility that perhaps phenomenal/experiential continuity obtains across the continuum, although with different degrees of reportability, due to variations in the spatiotemporality of ROM maintained. Interestingly, the general EEG distribution during absence seizures is primarily localized in bilateral frontal association and associated anterior subcortical structures while sparing the LGN and occipital cortex (ibid.). So if conscious experience can be generated locally, then visual consciousness would be spared even if the frontal disruptions preclude reportability or memory of those experiences.

The distinction between conscious experience and reportable conscious experience is one very familiar to neuroscientists and philosophers of mind and there is both experimental and neuroimaging evidence for this distinction. Perhaps the most famous experimental support for this distinction is George Sperling's (1960) experiment, in which subjects are briefly presented with 3x3 letter arrays and have to briefly report what they have seen. Subjects reported having seen the whole grid but on average could report no more than 4 of the 9 letters. But if asked, after the display, about the contents of any single row, subjects tended to perform successfully. My point is not to get into the ultimate ramifications of this experiment – a lot has been written on it – but to point out that it demonstrates a clear distinction between experience (of the whole) and reportability (of part).

This, by itself, can't help the ROM theorist much because there is a clear disanalogy between the experiential/reportability cases in absence seizures and the Sperling experiment; namely, only subjects in the latter were aware that there was something experienced but unreportable. So the point is just to emphasize the validity of the distinction. And there is neuroimaging support for this distinction as well. Reportability, but not necessarily simple sensory consciousness, depends on frontoparietal and memory circuits. As discussed in the previous chapter, the neurobiological basis of consciousness is a disputed topic, so too unwieldy to cover here to any depth, but, again, the point is that a solid basis for distinguishing simple conscious experiences and reportable conscious experiences does exist. And this is something most NR-theorists don't question. Grush's TEM, e.g., relies heavily, as we've seen, on an overwriting thesis that explicitly formalizes the idea that people have conscious experiences that are in principle inaccessible, unreportable and unaccompanied by any sense of discontinuity.

So a live possibility is that all cases of absence seizures involve conscious experience, it's just that "typical" cases are unreportable. Perhaps these experiences cannot be committed to memory (due to oscillatory disruption in memory circuits) or are immediately forgotten (analogous to the overwriting axiom of the TEM). But since there is plausibly never a loss (or a full loss) of consciousness on any absence seizure, there is no discontinuity to be accounted for. To save ROM on this argument, all that has to be shown is that ROM continues to obtain, even if in a decremented state, during absence seizures. And this is plausible given the EEG experiments and neuroimaging results. As mentioned, significant heterogeneity in the EEG and fMRI measurements remains through absence seizures – as opposed to the characteristics of slow-wave sleep or coma, e.g. In this respect it is important to note the findings of Vuilleumier et al. (2000), that the nature of experiential report during absence seizures correlated with different EEG signatures. These signatures of neural heterogeneity suggest that ROM still obtains in various networks of the brain, and those plausibly support unreportable conscious states. The idea is that the contraction and diminishment of ROM in frontal networks explains unreportability, but the continuance of ROM in posterior networks – as has been experimentally demonstrated (Holmes et al., 2004) – explains the absence of an experience of discontinuity. As this explanation can't be ruled out, the objection seems inconclusive to my mind.

Although I think the foregoing diffuses the objection, there is another interesting possibility that is worth mentioning. Suppose it is experimentally shown that the ROM networks required for consciousness are transiently destroyed during typical absence seizures (evidence of conscious impairment by motor and verbal tests is typically no longer than 2 seconds (Goldie and Green, 1961) (but note that behavioral tests are inconclusive evidence of unconsciousness, in any case)). And suppose it is also shown that there is no experimental evidence for an experience of discontinuity in subjects (note the epistemic leap from no evidence to a positive conclusion). Suppose all this, which is the strongest version of the objection. What is the ROM theorist to say?

The possibility I have in mind is that the strong and regular low-frequency oscillation that is at its highest amplitude during the transient unconscious state provides a stable framework for the return of ROM to the same harmonic ground, so to speak. What differentiates specious presents on ROM is phase reset in the low-frequencies. What I am suggesting is that the unnaturally long stability of the low-frequency rhythm without phase reset seen in absence seizures may actually provide a mechanistic explanation for what amounts to an unnaturally long specious present experience. Since the low-frequencies remain uncharacteristically regular, the natural rebound of the midand high-frequencies to their pre-ictal trajectories would reinstate a conscious experience with no sense of discontinuity, despite the objective lapse. This, then, is another possibility. Taken together, I think the objection is interesting but inconclusive.

6.2.5. Do Oscillatory Frameworks Imply ROM is an NR/Anti-Extensionalist Theory?

The final objection I'll cover in this section is that the oscillation-based integration windows featured in my explanation undermine my commitment to R-theories and extensionalism. The challenge is based on the idea that oscillation-defined temporal integration windows are discrete processing entities that generate discrete frames of conscious perception (White, 2018). But, the argument goes, discrete frames of conscious perception sit most naturally with NR-theories. And if the temporal integration windows at the neurodynamical base of my view are brief and discretely periodic, then a commitment to brain-experience resemblance could ironically imply discrete conscious episodes, along the lines of NR views.[78]

In response to this objection, ROM formalizes the view that there is no discrete processing at the level of neuro-vehicular dynamics realizing conscious phenomenology and representation (cf. Ogmen, 1993). Total phase resets mark discrete events, but partial

[78] At this point it's important to repeat my argumentative aim. Instead of showing that an oscillatory framework, like the ROM theory introduced below, is incompatible with atomist views, my goal is simply to show the natural consonance of the ROM oscillatory framework and extensionalism. In one sense, this might be considered a concession to the NR theorist. But in another crucial respect it is not. As just briefly explained, due to the discrete nature of individual oscillatory dynamics, the default/received view in the literature has been that an oscillatory framework sits much more comfortably with, and almost implies, an atomist view of one kind or another (cf. Ruhnau, 1995; Metzinger, 1995; Busch and VanRullen, 2014). Demonstrating the strong congruence of ROM and extensionalism shows the coherence of my approach, on the one hand, and arguably shifts a burden of argument to NR theorists, who have generally based their arguments on neuro-mechanistic grounds (Grush, 2005; Lee, 2014).

phase resets, as employed by ROM to account for phenomenological continuity, are not discrete.

Specifically, individual oscillations or oscillatory components only contribute to the realization of immanent consciousness when part of a complex, *hierarchical* ROM manifold of *interdependent* oscillatory components. This idea coheres with experimental evidence showing that while brain states characterized by high-amplitude single oscillatory dynamics invariably correspond to unconsciousness, conscious states always correlate with "desynchronized"[79] EEG signatures. ROM theory provides an explanation for these observations.

So, although oscillations may be individually periodic and in that sense discrete, ROM holds that this does not imply that oscillations have neuro-functional relevance *as* discrete entities. Rather, the realization of immanent temporal consciousness is a function of a *continuous* ROM manifold, whose continuity is comprised of interdependent and overlapping oscillatory dynamics/circuits. It is that continuity that does representational work, and *it is that continuity at the vehicular level that is resembled by the resulting continuity at the phenomenological level.*

The critical upshot, then, is that the theoretically discrete nature of individual oscillatory components is tangential to understanding the nature of the neurodynamical realizers of temporal experience. If the oscillatory dynamics underpinning even basic temporal experience are multi-dimensionally hierarchical and interdependent, then the objection that anti-resemblance theorists throw at resemblance theorists, based on the

[79] There is a critical ambiguity. "Desynchronized" could be taken to imply an overall lower coherence of brain activity/processes. However, on ROM, the relevant sense of desynchronization implies a higher coherence of brain activity because it allows more complex hierarchical interdependencies. Hence, "desynchronization" is necessary for realizing complex coherent brain processes.

discrete nature of individual oscillatory dynamics, evaporates. Ronconi et al. (2017) presage this idea when they convincingly argue from their EEG experimental findings that,

> In theory…a hierarchy of [temporal windows] could help to mask the presence of perceptual samples/cycles, which is important, given that the presence of discrete windows in sensory processing does not mean that conscious perception is typically discontinuous…" (p. 13435).

ROM adds the critical point that although discrete processing windows can be recognized in the form of discrete oscillation-constituted temporal processing windows, it is only via complex hierarchical interdependence that oscillation-realized temporal windows collectively generate temporal representation and phenomenology.

Together, the previous paragraphs thus show how ROM supports an R-theory view. Not only does the ordinality of experiential content follow the ordinality of ROM dynamics, but the phenomenological continuity amidst representational discreteness experienced in and between specious presents is isomorphic to the continuity of ROM dynamics (Buzsaki, 2006). As phase relationships between frequency bands change, so changes the fundamental harmonic that determines the essential extent of the specious present as a representational bottleneck, but the continuance of partial phase coherence in the multiplexed manifold provides a mechanism to explain phenomenological continuity. As I'll briefly discuss in chapter 7 and introduced in chapter 3, even some anti-extensionalists are doubtful that basic atomist views can explain the *felt continuity of experience* (Wiese, 2017; Wiese and Metzinger, 2017). ROM provides a plausible account and should shift the burden of argument to the anti-extensionalist.

6.3. Overview of Philosophical Objections

There are two main types of philosophical objection to my characterization of ROM: attacking its extensionalism (Grush, Lee, Chuard) or its commitment to the specious present (Arstila, Prosser, Chuard, Le Poidevin). In what follows, I show how ROM theory has resources to successfully respond to a host of challenges. My replies are necessarily schematic however. First, there simply isn't sufficient space to delve into great depths while achieving my main aim of demonstrating the general plausibility of ROM by countering a wide gamut of objections. Second, my replies utilize mechanisms and features of ROM theory that I have introduced and motivated, but have not had, sufficient space to rigorously argue for. A skeptic can always press that my "solutions" are unproven and speculative. Such is the nature of original theoretical discourse. My goal is to present a coherent picture supported by neuroscientific evidence, which is the reason for the wealth of scientific references.

6.3.1. Arguments Against Extensionalism

6.3.1.1. Grush's Central Critique of Extensionalist Theories[80]

Rick Grush agrees with the strategy of explaining temporal consciousness via the specious present doctrine. His Trajectory Estimation Model (TEM) posits that brain networks continually generate intervallic temporal content as a means of predicting

[80] This is aside from his famous arguments against extensionalism based on temporal illusions. I presented chapter 4 as an extensionalist reply to that key challenge, and professor Grush was generous enough to admit its success in that regard (per. comm.).

stimuli trajectories and optimizing responses to them. Grush is skeptical, however, of the extensionalist idea that individuating temporal content during an instant can be representationally parasitic on the embedding temporal trajectory of which it is a part. In response to this interval priority of ROM (and other extensionalist views), Grush (2016) points out a potential dilemma. How, he asks, can we understand the idea that events at time t depend in some way on events at t+1? (a) If the idea is that future events actually reach back and affect events at an earlier time, Occam's razor and physics rule this out (since we can account for worldly events without resorting to such mechanisms). (b) If the idea is that future events can be accurately characterized by predictions, then it is innocuous (since only descriptive and not explanatory). Either way, these routes to prioritizing intervals over instants – by making the conscious content of an instant dependent upon subsequent activity (i.e., a surrounding interval) – look unpromising.

What isn't considered, however, is the idea shown via AM above: that if temporal order contents are realized by ROM dynamics, then activity at different temporal points will contribute to the eventually realized representational content. The general defense of the intervallic individuation of temporal representational contents is based on the differential latency idea that the extended vehicular processes generating representational content X' from stimulus X are causally influenced by hysteretic neurodynamics occurring both prior and subsequent to X (cf. Purushothaman et al., 1998; Patel et al., 2000; Bedell et al., 2003; Ogmen et al., 2004; Baldo and Caticha, 2005; Bedell et al., 2006; Kafaligonul et al., 2010; Bachmann, 2013). As illustrated in the AM case above, and in the flash-lag and other illusions in the cited papers, complex latencies subvening various representational contents integrate stimuli/information over a dynamically evolving interval, which provides a defense of extensionalist commitments against Grush's supposed dilemma.

6.3.1.2. Lee's Trace Integration Argument against Extensionalism

Geoffrey Lee offered an important argument against extensionalist views in his (2014a) paper, which claimed that the vehicles of representation must be simultaneous from the point of view of a cognitive system, for it is only under such conditions that the total informational content is sufficiently accessible, and can therefore represent particular moments (Lee, 2014; p. 5). He takes his argument to therefore show that "temporal experience is realized by states that do not code time by time itself, but rather use 'simultaneous'…coding..." (ibid.; p. 19, and Busch and VanRullen, 2014). If Lee is correct about his argument's implication, it undermines extensionalist views like ROM that posit represented time resembles brain time. Now, the key question to ask is what to make of the concept of simultaneity in play.

As Lee explains, "because experiences require extended processes like neural firings in order to exist" (ibid.; p. 4), this means that his notion of simultaneity is not an instantaneous one. But if we take his concept of simultaneity to refer to a temporally extended window, it no longer follows that his arguments based on simultaneity prohibit the coding of time through time itself. There are three main points.

First, even within very brief intervals, multiple frequency bands can multiplex in ways *that preserve the temporal relations of distinct frequency bands through phase coding and frequency coding* operating at distinct timescales – this is one of the features demonstrated by scale-invariant ROM dynamics (Buzsaki, 2006, Jensa and Muller, 2013; Maris et al., 2017). Simply maintaining the temporal relations is sufficient for a resemblance account of simultaneity and succession. But what about extension and continuity?

Here, the extended nature of "simultaneity" in play is arguably no different than the extended temporal windows generated by oscillatory dynamics. Since Lee gives no durations, something along the lines of ROM machinery can't be ruled out. In this case, "simultaneous processing" would just be a proxy for the oscillatory integration windows discussed in chapter 5. Moreover, the overlap of oscillatory integration windows is a sufficient explanation for continuity.

Lastly, once we admit extended windows of integration, it isn't clear that we can't explain simultaneity and succession in terms of differential latency accounts that also manifest temporal isomorphism, as in the AM model in chapter 4. As mentioned, we have no argument for how extended or truncated Lee's extended simultaneity is, so we can't rule the foregoing out. The upshot is that Lee's argument falls short of demonstrating his claim.[81]

[81] Viera (2016; p. 144) articulates how Lee (2014) levels another objection against extensionalist accounts: that the "temporal order blindsight" phenomenon explained in chapter 1 violates the mirroring/resemblance principle. The objection is that how can an experience accurately represent two stimuli as occurring non-simultaneously but of indeterminate order? Prima facie, if the extensionalist posits temporal asymmetry of X and Y, then it must represent the ordinality of X and Y. If you don't have neuroscience to advert to, this may seem like a significant problem. However, as we saw in chapter 4, this is relatively easily explained via the neuroscience of ROM's differential latency circuitry. Specifically, the oscillatory rates of feedforward and feedback signal generators are distinct, and it is not only possible, but inevitable, that multiple temporally-distinct feedforward signals will be occasionally be integrated into a single feedback signal. The result is that while some information flows in the brain signal stimuli asymmetry, the details of that asymmetry are unavailable for conscious awareness or report – i.e., temporal order blindsight. The upshot is that this additional argument against extensionalism fails.

6.3.1.3. Chuard's Missing Content Argument against Extensionalism

Chuard (2017) argues that extensionalist views suffer from a "missing content" objection. All agree our experience of a succession of specious presents feels continuous, extended and flowing (Dainton, 2010; Rashbrook-Cooper, 2016; Wiese, 2017). Extensionalist views, Chuard argues, have a sufficient account of continuity *within* specious presents, but how can they account for temporal relations of continuity and flow *between* events represented in experience?

As discussed, if specious present durations are delimited by slow frequency oscillatory phase reset and modulation (cf. Canavier et al., 2015), then we have an explanation of how variations in the same mechanism can account for both discrete and continuous representational content: since phase resets, during waking states, are always only partial, the decoherence generated by phase reset can account for the phenomenology of change/discreteness, while the continuity of the oscillatory components that remain multiplexed, plus the continuity of neurodynamical activity in reentrant circuitry, accounts for the phenomenology of continuity. In short, then, the oscillatory and reentrant coherence that persists through partial phase resets are the neurodynamical basis for the representation and phenomenology of continuity between specious presents.

6.3.2. Arguments Against the Specious Present Doctrine

6.3.2.1. Argument Against the possibility of Discrete Content between Specious Presents

The explanation of ROM included the claim that phase reset/modulation in reentrant circuits might explain how successive specious presents can have both discrete and continuous representational contents. This is an original theoretical claim. A few indirect arguments against parts of my strategy may be thought to come from Arstila (2017), who writes, "First, the idea that the contents of succeeding specious presents are experientially isolated has the consequence that we would not experience the temporal relations between the contents belonging to different specious presents. This is phenomenologically implausible (Dainton, 2010). Second, there is very little empirical evidence for the idea that mental states succeed each other discretely." (p. 9).

In defense, phase dynamics of ROM have all the right features to handle this case. Evidence shows that phase resetting and modulation co-occur with attentional shifts (both external and internal) and so are natural markers of representational change (Low, 2009; Kayser, 2009; Kosem, 2014; Canavier, 2015; Voloh, 2016), yet they don't require implausible experiential discreteness because partial phase resetting does not destroy all coherence between oscillatory bands nor, therefore, on ROM, a sufficient degree of oscillatory continuity to explain the phenomenological continuity amidst changes in representational content.

6.3.2.2. Arstila's Argument that the Specious Present is Experimentally Unsupported

In arguing against the phenomenological reality of the specious present, Arstila (2017) discusses the experiments of Vincent Di Lollo (1980) in some detail, claiming they are hard to reconcile with the specious present doctrine. He argues that subjects' experiences in these experiments do not include just-past phenomenal contents, as the specious present requires. In more detail, subjects were tested on their abilities to detect a missing dot in a 5x5 dot grid presented in 2 sequential presentations of 12 non-overlapping dots. The key variable was the duration of the initial presentation of 12 dots (10ms, 40ms, 80ms, 120ms, 160ms, 200ms, etc.), which was followed by 10 ms of empty screen and then a 10ms presentation of 12 other dots. In all cases, the two presentations combined left out 1 dot, and identifying the location of the missing dot was the experimental task.

The results showed that subjects were highly successful when the lead presentation lasted 80ms or less; however, for longer initial presentation durations, performance markedly deteriorated in proportion to initial display length. Arstila argues that this is in conflict with the specious present doctrine in two ways. First, since the trailing display was always at the same onset and duration relative to the leading display offset, "the trailing display [should] change from occurring now to just-occurred and then to further past in the same way in all experimental conditions and the performance should remain the same…(2017; p. 7-8). Secondly, the unavailability of the leading dot presentations in the longer display durations is at odds with the requirement that the specious present permits "immediate and sensible" awareness of the recent past.[82]

I accept the basic finding that with increasing lead display times, subjects' performances (at detecting the missing dot) deteriorate in proportion. Arstila suggests that this shows a failure of specious present dynamics, but there are contrasting interpretations with greater neurodynamical support. First, note that oscillatory multiplexing highlighting alpha frequency, which is a foundational frequency shaping activity in sensory cortices, would predict that continuous stimulus durations beyond a single cycle (beyond ~80-120 ms stimulus presentation) would initiate a new cycle of sensory representation of the initial stimuli. The persistence of activity representing the leading display would inhibit registration of the trailing display for at least 80ms – well beyond the 20 ms relevant to the experiment (10 ms of empty screen + 10 ms trailing display). Notice that alpha dominance of the ROM, while plausible, is not necessary: the conclusion generally holds for integration windows at frequencies lower than low-beta. Hence, the trailing stimuli are never sufficiently processed for representation and accurate performance.

Second, this picture shows why Arstila's abovementioned contention – that because the time between displays is always 10 ms, that performance on a specious present view should be consistent – is false. There is neither a requirement that the specious present be of unvarying size (on a ROM view, it sensitively depends on which oscillations are multiplexing in reentrant circuits and the ongoing timing of phase synchronization/desynchronization (cf. Crick and Koch, 2003)), nor that previous stimuli

[82] Rick Grush notes, "I think his objection is misguided. The doctrine is about the contents, not about whether they are accurate, and whether specific timing of stimuli can make them inaccurate in various ways" (per. comm., 2020).

do not establish a reference against which representational activities occur (they do).[83] Rather, the multi-cycle integration of the leading neural activity explains the interference in processing the trailing stimuli, the performance inaccuracy, and the variability between trials. Thus, the results don't support Arstila's argument against the specious present. In fact, it seems to show that brains and minds can't work by any instantaneous "mechanism" because, if it did, the trailing stimuli would be fully represented during the 10ms they were shown, but this doesn't occur (cf. similar arguments against instantaneous content views by Herzog (2016)).

As a final consideration, note that there are plenty of phenomena in which the precise timing of sequential stimuli generates a perceptual gap – attentional blink, repetition suppression, inhibition of return, etc. Not only would inferring the falsity of the specious present doctrine on the basis of the existence of these phenomena be unsound, but a mechanism to explain representational gaps is at hand and has experimental support: oscillatory phase modulation and phase resetting (Achuthan & Canavier, 2009). If representational activities develop over time due to changing oscillatory multiplexing, then phase resets naturally explain (i) the transition between representational contents and (ii) why stimulus presentations falling during phase resetting would go unnoticed. In fact, many of the interstimulus intervals that correlate with perceptual blindness and attentional gaps correspond to the slower oscillatory periods involved in sensory processing (alpha), attention (theta) and perception (delta) – (e.g., Schroeder and Lakatos, 2009; Canolty and Knight, 2010; Calderone et al., 2014; Spaak et al., 2014; Gruber et al., 2014; Arnal et al., 2015).

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[83] "…a dynamics-based…timing device…depends on the previous stimuli, independently whether these recent stimuli are relevant to the task at hand" (Buonomano, 2014; p. 338). This is true for ROM theory.

6.3.2.3. The Argument Against the Specious Present from Pure Phenomenology

Although this was covered in chapter 3, it is apt to recapitulate it here in condensed form. Le Poidevin (2007), Arstila (2016a/2017) and Prosser (2017) all argue for the superfluity of the specious present since cases like "pure motion" provide a potential explanation for direct experiences of motion.[84] Pure motion is a label to characterize the experience of motion without an explicit representation of motion. There, some of the following objections were discussed.

Is the phenomenon correctly described? Maybe it's an error to think we're not having explicit representations of motion, even if describing those representations is challenging.

Is pure motion actually an alternative to specious present views? Specious present views are founded upon the axiom that motion experiences require temporal intervals and hence experience has intervallic content. Why not think the pure motion experience supports the existence of the specious present directly? Is the cinematic theorist involved in some doublespeak here?

Lastly, *we are given no argument that pure motion phenomenology isn't generated by extensionalist processes themselves*. For all that is said, the extensionalist can adopt the "pure phenomenology" phenomena for herself. Arstila's basic (2017) explanation for how these experiences of motion come about without representation of objects explicitly changing locations adverts to the relationship between higher- and

[84] There are differences in their views, but they share enough in common to rationalize a general rejoinder.

lower-level processes. The idea is that a higher-level mechanism receives a signal from an encapsulated mechanism indicating that motion/change/causality/succession has occurred (which we experience), without receiving a detailed signal from low-level processes about explicit representational change (hence no experience of localized change). Interestingly, as my explanation of AM shows, ROM also incorporates hierarchical processing and partial representation based on oscillatory differences. Moreover, the account of "temporal order blindsight" explicitly adverts to a distinction between processes at different levels of abstraction differentiated in terms of simultaneity and non-simultaneity. This obviously reflects the spirit of Arstila's mechanistic account of pure phenomenology. So why should "pure phenomena" make us question the specious present doctrine and infer a cinematic view? The account herein is even more developed and supports an extensionalist view. Thus, even granting pure phenomenology is correctly described, it certainly can't be concluded to support a cinematic view.

6.3.2.4. Arguments Based on the Dis-unity of the Specious Present

Astila (2017) makes four objections about the dis-unified state of the specious present concept.

First, he argues that there is no fixed interval length for the specious present. This is not a problem for ROM, which holds that it is neurodynamically and experimentally much more sensible to hold that the specious present has a slightly variable length that sensitively depends on ROM circuit integration properties, and which helps explain both experimental and introspective variation in immanent temporal experience (cf. White (2018)).

Second, Astila notes that there isn't a single choice of specious present duration that could satisfy all the phenomena appealed to by specious present theorists. I'm sympathetic to this claim. My interest is set at liminal levels – those appropriate for immediate, unified and continuous temporal phenomenology.[85]

His third objection is that the specious present theorist can't dodge these objections by positing a flexible specious present interval: "One problem concerns the mechanisms determining the length of each specious present: how do we settle beforehand when the second stimulus, if there is one, might appear so that each specious present is suitably extended to include it and to bring about an experience of causality or succession?" (pp. 12-13). The premise here is empirically unsupported though. Experiments routinely show how easy it is to cause subjects to experience perceptual illusions by preventing accurate experiences of causality or succession. In fact, it is a feature of a flexible specious present view like ROM, not a bug, that it can account for attentional and performance errors of various kinds – those generally stemming from erroneous feature binding.

Arstila final point is something I have been independently considering: the possibility that there are multiple specious presents. I think this is a highly interesting

[85] One would like numbers, but there are lots of reasons to shy away from that game. That said, I put a wager on ~750 ms of content as a strong candidate for the mean duration represented in the specious present, which James (1890) cites as being the optimal duration of temporal reproduction. Perhaps ~750 ms optimally characterizes the typical duration of a perception-action cycle. Another interesting fact about 750 ms is that it falls squarely in the processing speed of the delta frequency (1.33 Hz), which has been shown to have profound correlations to timing in the brain, to intramodal temporal coherence (Kosem, 2014) and temporal experience in general (e.g., Schroeder and Lakatos, 2009; Canolty and Knight, 2010; Calderone et al., 2014; Arnal et al., 2015). Interestingly, this duration is ~3 times longer than Grush's (2015) TEM, designed to explain just the 'now' portion of the *triadic* 'just-past, now, about-to-be' content of the specious present.

idea, but one too complex to discuss here. I do, not, however, agree with Arstila that it is a big problem for specious present theorists to admit this possibility. As long as the various versions of the specious present *share a basic mechanism (like ROM)* – having different functional durations, perhaps as a result of being realized by ROM circuits of different spatiotemporal extents – this well may be exactly what we need to unify theories of temporal experience under a common banner (cf. Arstila and Lloyd, 2014; Lloyd and Arstila, 2014).

6.4. Conclusion

This chapter has considered a host of objections, from the neurobiological to the purely philosophical.

Regarding neurobiologically-based challenges, I have argued, using experimental evidence, that the ROM circuitry and latencies are robust. I have provided two alternative explanations for the objection that absence seizures violate ROM's continuity thesis. The first appears to diffuse the concern, while the second provides a novel ROM-inspired explanation consistent with the strongest form of the objection. Lastly, I considered the objection that the oscillatory framework implies an NR-view, totally contradicting ROM. There I explained that the multiplexing inherent to ROM requires positing a continuity of oscillatory rhythms that totally neutralizes the objection from oscillatory discreteness.

Regarding philosophical challenges, I looked at those objecting to extensionalism and those to the specious present framework.

Objections to Extensionalism: Against Grush, I argued that ROM's differential latency account vindicates an interval-based metaphysics of the specious present, which appears to silence objections based on requiring the temporal content of instants to have metaphysical priority over intervals. Against Lee's simultaneity argument, I pointed out that the extended concept of simultaneity he employs fits nicely with ROM's oscillatory framework and thus is ineffective. Against Chuard's objection that extensionalists can't explain the continuity objection, I rehearsed ROM's mechanistic account, which posits overlapping specious presents connected by conserved phase relations among multiplexed oscillations.

Objections to the Specious Present: Against the objection about successive specious presents having discrete contents, I pointed out that the phase-decoherence between previously multiplexed rhythms mechanistically accounts for discreteness. Against the objection of experimental non-support for the specious present, I reexamined experimental findings in light of a highly-supported experimental oscillatory framework. Against the attempt to account for our self-evident temporal experience without the specious present via pure phenomenology, I presented two arguments: that pure phenomenology violates the cinematic metaphysic and that pure phenomenology can be reinterpreted as an extensionalist phenomenon. Lastly, against the arguments that the specious present is a dis-unified concept, I showed how the flexible duration of the specious present required on a ROM account solves any arguments presuming it should be characterized by fixed parameters.

I turn now to the future prospects of ROM theory by focusing on how it comports with some important extant views and approaches.

Chapter 7: ROM and A Look Ahead

7.1 Introduction

In this chapter I'll look at the relationship between ROM and some extant theories to help situate it in broader conversations occurring throughout academia. I have two main aims. First, I want to show how ROM instantiates very influential versions of models usually only discussed in the neurosciences; specifically, state dependent networks and population clocks. Secondly, I want to illustrate its resonance with one of the most influential theories of modern philosophy and science, the class of theories of the cognitive economy falling under the (rough) synonyms of "generative," "predictive," or "emulative" models.

7.2 ROM and the Neuroscience of Timing

7.2.1. Introduction

This section concerns itself with the specific relation between ROM theory and the neuroscience of timing. The neuroscience of timing focuses on *metric timing* phenomena involving a measure of interval or duration, which "require some sort of timing device to solve" (Paton and Buonomano, 2018; p.688). This is in contrast to *time-dependent* phenomena, which "are defined by their temporal properties…but do not require a clock or timing device to solve," such as tasks that concern themselves with simultaneity or ordinality, e.g.

The specious present debate in the philosophy of temporal perception, for better or ill, has revolved around apparent motion (AM), as much as any other phenomenon. However, AM is technically a time-dependent phenomenon, as opposed to a metric timing phenomenon (Paton and Buonomano, 2018) and so falls outside of the basic purview of neuroscience timing models.

Thus, there is, unsurprisingly, clear disparity between the independently developed approaches taken in the philosophy of temporal consciousness and those in the neurosciences. While philosophy has employed time-dependent phenomena to debate the nature of temporal consciousness, neuroscience has, understandably, required more quantitative approaches centered around timing tasks of various kinds (interval timing, pattern timing and motor timing, e.g.). What remains, then, is the task of building a bridge between the ROM model, fleshed out in terms of (but not limited to) a time-dependent AM phenomenon, and the neuroscience of timing.

The purpose of this section is to show that not only is there a natural bridge, but that *ROM theory actually instantiates two types of intrinsic neurodynamical timing models, the state-dependent network (SDN) and population clock*. In brief, ROM as well as SDNs and population clocks, intrinsically code time through circuit neurodynamics. Explanation follows below, but the present point is that SDNs and population clocks are key classes of neuroscientific timing model and if ROM instantiates them, then the aforementioned gulf between the philosophy and neuroscience of time can be bridged, at least theoretically.

7.2.2. Neuroscientific dichotomies

To juxtapose ROM as a theory of the perceptually-defined specious present with the neuroscience of timing, it is necessary to discuss the applicable scope of neuroscientific discussion. Three dichotomies will be helpful in explicating the relation of ROM to the neuroscience of timing. They are the following:

(1) Subsecond vs. Suprasecond timing models

(2) Sensory vs. Motor timing models

(3) Dedicated vs. Intrinsic timing models

7.2.2.1. Relevant temporal scope

(1) The first important distinction contrasts subsecond with suprasecond timing models. There is significant evidence showing the circuitry involved in each case is distinct. The evidence comes from pharmacological studies (Rammsayer, 1999), psychophysical studies (Rammsayer et al., 2015), as well as imaging studies (Lewis and Miall, 2003) (Paton and Buonomano, 2018). These studies all show that discrimination of very brief duration, on the scale of ~100ms or so, seems to involve different circuits than discriminations involving suprasecond intervals – on account of involving different chemical mediation, showing different psychophysical graphs, and highlighting different brain activation patterns (ibid.). This is relevant because there is general agreement that

the representational content of specious present is probably a second or less – at least many of the leading discussants hold that view (see Dainton, 2010, for general discussion). Because R-theorists hold a vehicle-content isomorphism axiom, and NR-theorists tend to think vehicular events are shorter than their corresponding represented content durations, philosophers interested in accounting for the specious present will agree that a distinction between subsecond and suprasecond circuit dynamics is not only relevant but probative.

In light of these considerations, we can conclude that subsecond timing studies are those most directly relevant to the present discussion. The point is a general one about linking the ROM model with the neuroscience of literature. It would take us afield to presently consider some collection of subsecond timing researches. However, the ROM model holds that the spatiotemporal size (and hence complexity) of a ROM network isomorphically determines the spatiotemporal representational content of the specious present. So the capacity to sustain larger ROM networks causes the generation of more extended spatiotemporal representational content. The upshot of this is that it is unclear whether the ROM model can't be extended to explain some suprasecond phenomena – it depends on the capacity of a brain to sustain ROM, an open empirical question (but see Varela et al., 1991; Dehaene et al., 2006).

7.2.2.2. Sensory and Motor Timing Models

(2) The second important distinction in the neuroscience of timing is between studies in which subjects respond in a simple way to exogenous cues (sensory tasks) vs.

those in which subjects have to endogenously generate action to anticipate, predict or reproduce cues or temporal patterns (motor tasks). This distinction is relevant to this discussion because they involve different kinds of models and because AM is a paradigmatically sensory event. To experience AM requires no motor activity of any kind (though, as mentioned in chapter 4, motor cortex can influence AM experiences (Jantzen et al., 2004)). Being that the aspirations of ROM outstrip explaining just AM, I will look at motor models of timing, too.

Two kinds of sensory timing models are discussed in Paton and Buonomano (2018): (i) spectral models and (ii) state-dependent networks.

(i) Spectral models are temporal filters created by various time constants of neurons. Directly put, in spectral models/temporal filters, the duration of the relevant process grounds a basic timing mechanism that can naturally code for an equivalent duration. The simplest spectral models, delay lines, create temporal filters via natural signal delays through neural tissue; they are applicable over 10s of ms and were first devised in the context of interaural axonal time delays, and later extended to include dendritic delays in granule cells in the cerebellum, applicable up to a few hundreds of ms (Braitenberg, 1967). Other spectral models are based on other neural time constants, including potassium and calcium channel kinetics, the time course of metabotropic receptor activation, as well as short-term plasticity dynamics (Paton and Buonomano, 2018). The time course of these constants, and hence the period of these filters, ranges between tens to hundreds of ms (ibid.). Accordingly, these models were initially important for explaining coincidence detection at extremely high temporal thresholds.

Spectral models are not at all at odds with ROM, but they fly considerably under its implementation-level radar. It could be incorporated as a component to explain the subterranean neurodynamics underpinning the generation of basic oscillatory behaviors, but will not be covered here. There is another reason for abstaining from further discussion of spectral models. Although they provide interesting models of experimental data at very short time scales, Buonomano (2000), correctly, to my mind, claims that they fail to account for more ecologically-relevant, prolonged types of temporal representation that require the integration of successive events – such as the fusion of flashes characterizing AM. I turn to SDNs.

(ii) As characterized by Paton and Buonomano (2018), state-dependent networks are

> general and powerful computational models…to account for how cortical circuits might respond selectively to the spatiotemporal structure of complex stimuli such as spoken words….Conceptually, the SDN model proposes that the response of a population of neurons at any moment in time is intrinsically dependent on the interaction between the current input and the current state of the network (i.e., the context imposed by the previous sensory events). The internal state in turn is defined not only by which neurons are currently firing (the active state), but by the state of time-dependent neural properties…referred to as the hidden state…such as which synapses are currently facilitated or depressed state (693-4).

As explained in detail already, ROM is a theory of how "cortical circuits might respond selectively to the spatiotemporal structure of complex stimuli." It should also be very obvious given the AM model presented in chapter 4 that the activity at each step of the model "is intrinsically dependent on the interaction between the current input and the current state of the network," which is defined in part by the hidden state (well described by the parameters of the ROM model). As a result of this dependence, "the state of a network at any point in time encodes not only the present but also the past" (Buonomano and Maass, 2009; p. 114) – quite apt for a theory of the specious present. In light of the ROM model of AM, it should be quite clear, at least based on what's been said so far, that ROM instantiates a version of an SDN.[86]

Although the AM model is best described as a purely sensory task and so presumably best described by a sensory timing model, it is worthwhile to look at models of motor timing as well, and for two simple reasons. One, sensory and motor processes form a continuum: motor timing is based on sensory cues and sensory timing is behaviorally accessible through motor acts. And two, many motor processes take place in the sub-second range. Consider typical speech or art performance (music, dance, sports) acts for instance – many if not most such actions occur on a sub-second scale.

As outlined in Paton and Buonomano (2018; p. 698), there are 3 main classes of motor timing models: (i) oscillator-based models, (ii) ramping models and (iii) population clocks. I will look at each in turn in relation to the ROM model.

It might be assumed that the ROM model instantiates, quite obviously, an (i) oscillator-based model, but the relationship is a bit complicated, since there are both single and multiple oscillator models. Single oscillator models – also called "internal clocks" or "pacemaker-accumulator" models – were constructed in resemblance to man-made clocks: an oscillator generates rhythmic pulses or ticks that are counted by an "accumulator" to generate a linear count of time and a memory faculty is employed to utilize the information in behavioral tasks – these were created to predict behavioral data

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[86] For those familiar with SDN axioms, ROM is *not* committed to the original proposition that SDN models are inactive without stimuli-driven excitation (cf. Paton and Buonomano, 2018). In fact, the ROM model, congruent with Buzsaki's (2006) treatment, is committed to the existence of endogenously self-perpetuating brain circuit activity.

(which in some simple single-stimulus experiments they accomplish well), but not to be neurobiologically realistic (ibid.). The analogy to a computer should be clear, as should the fact that these simple models bear no resemblance to ROM, and so further explication of the model would be tangential.

Multiple-oscillator models, however, appear roughly consonant with ROM, with some important differences, to be discussed shortly. ROM is a model in which multiple oscillators generate mutually-coherent complexes, but they are generated by multiplexing oscillations into integrated reentrant circuits. These additional elements are a significant gulf between multiple-oscillator models as developed and ROM, but there remains a natural functional consonance: as illustrated by ROM's AM model, it is the temporal relationships between circuit dynamics that determine the temporal content experienced.

Moreover, the AM model relies on significant coincidence between signals and processing periods to generate coherent information flows (and hence representational content). This emphasis on oscillatory coincidence in the model's function can perhaps be extended in the lines developed by the innovators of the most detailed such model, the striatal beat frequency (SBF) model (Matell and Meck, 2004)[87]. They suggest that a 1 second interval might be encoded by the constructive interference of distinct oscillations. The idea is that these oscillations are mutually coincident once per second. For example

[87] The most well-known example of this kind of model is the Striatal Beat Frequency (SBF) model (see Miall (1989) for the beat frequency model; see Matell and Meck (2004) for a seminal paper on the SBF). Essentially, the model posits that stimulus onset causes a large scale phase resetting, synchronously initiating a host of randomly distributed oscillators with conserved frequencies and, therefore, oscillatory periods. The idea then is that stimulus intervals/durations can be naturally represented by oscillators with periods isomorphic to those stimulus intervals/durations, and the coincidence of stimulus and oscillatory intervals is detected by GABA-mediated striatal spiny neurons (ibid). Output from these spiny neurons to the thalamus can be utilized to guide time-sensitive behaviors. In this way, the interval or duration of external events can be measured and utilized through coincidence detection by encapsulated brain mechanisms. As will be shown below, this model, arguably the most currently popular interval timing model, shares a number of key features with the ROM model presented here.

(not theirs), every 3rd 3 Hz oscillation, every 4th 4 Hz oscillation and every 10th 10 Hz oscillation will temporally synchronize at 1 second intervals, potentially maximizing information transfer (cf. Fries, 2005). Without explicitly measuring time, the convergence of such oscillations will naturally produce a system potentially capable of timing 1 second intervals, or so it may be claimed.

In practice, the kind of multiplexing employed by ROM involves oscillations generated over large areas of cortex (increasing oscillatory sustainability through interneuron feedback mechanisms (Wang, 2010)), and with larger frequency separation (to help maintain integrity of independent signals amidst noise (cf. Karmarkar and Buonomano, 2007)). On ROM therefore, the more likely picture is that a slow wave oscillation with a fractional Hz (1/x) might ground 1-second timing by multiplexing once per second with other oscillations via phase coherence. Importantly, this flips the timing story described above. Multiple oscillator models, as just described, combine multiple oscillations to generate a timing signal transcending any of their individual periods (supra-period); however, ROM mechanics, as I unpacked them, typically operate sub-period: higher frequencies multiplex through phase coherence within the period of lower frequencies (sub-period). In this way, ROM helps explain the empirical finding that "[m]any rhythmic motor behaviors…are governed by the phase of neural oscillators" (Paton and Buonomano, 2018). So there are some notable differences. But there seems to be nothing in principle problematic that prevents oscillatory multiplexing from realizing an implicit supra-period timing system. However, given the existence of ultra slow oscillations (Buzsaki, 2006), sub-period dynamics may still be sufficient to account for all phenomenological data.

(ii) Ramping models have been important in describing a mechanism leading to motor action. Neurons typically display a monotonic increase in firing rate until a threshold is reached, at which point an action is performed. There is a vast amount of evidence linking ramping neurons in various frontal, motor and parietal cortices to action execution (Murakami et al., 2014; Jazayeri and Shadlen, 2015). Since ramping can far exceed the time constants of individual neurons, ramping behavior can be inferred to be a product of recurrent circuit dynamics (Reutimann et al., 2004; Lim and Goldman, 2013). One question asked of ramping neurons in the timing literature is whether they code for time per se, or whether they code for the decision-making process more generally – expectation, action preparation, etc. (having a temporal component as a matter of course) (Buonomano, 2014).

The relation between ramping models and ROM is fairly open. There is nothing preventing ROM models from implementing ramping neurons as part of its vehicular mechanisms. ROM has the flexibility to incorporate all manner of empirically supported neural processes as vehicular elements generating its basic oscillatory dynamics. As a result, nothing more will be said here on the matter.

(iii) Population clocks are models in which time is intrinsically encoded in the changing activity of neural populations (Buonomano and Karmarkar, 2002). More specifically, they are "models in which a given point in time is represented by a unique pattern of spatial activity within a neural network. Distinct patterns of activity in the network unfold over time" (Buonomano and Laje, 2010; glossary). Population clocks are the motor side of the state-dependent network model of sensory timing. Together, they aspire to provide a unified intrinsic model of timing. The mechanics of population clocks require some explanation.

In essence, population clock models abstract away from myriad neural details to represent all (n-) active neurons as individual dimensions in an n-dimensional state space, the entirety of which provides a unique global picture of active neural firing. Since the spatiotemporal pattern of active neurons is continuously changing, the location in n-dimensional space continuously changes as well. The changing path through state space is called a trajectory, and it is a representation of the dynamically changing population-level activity in the represented neurons (Buonomano and Laje, 2010; Buonomano and Maass, 2009).

In population clocks, like SDNs, spatiotemporal properties are represented together – one of the significant parallels with ROM theory. The temporal properties of population clocks are intrinsic to the temporal properties of the neural trajectory. Remarkably, there is experimental evidence that the speed of the model's trajectory linearly predicts subjective estimates of duration – i.e., higher trajectory change rates correspond to longer estimated duration estimates (Gouvea et al., 2015). That is, the population clock represents the neurodynamical trajectories occurring in the brain and the speed of change of the modeled trajectories correctly predicts subjective estimates of elapsed time. The faster the trajectories are changing during an interval – the more change represented during that interval, in other words – the longer subjects estimate an interval to be. This is fascinating work, and it shows how a sense of time emerges intrinsically out of changing neurodynamical activities, exactly as instantiated in the ROM model.

For present purposes, a few points will suffice. As the AM model illustrated, ROM operates as a population clock, especially in regards to its use of population-level dynamics to generate intrinsic temporal properties. Similarly, both ROM and population models provide theories in which spatial and temporal computation is inevitably intrinsic and intertwined. Lastly, the resources of state-space neural trajectories offer new opportunities for enriching understanding of the ways ROM theory can illuminate the specious present.

7.2.2.3. Dedicated vs. Intrinsic Timing Models

(3) The third key dichotomy to discuss is between competing types of timing models. The first timing models, constructed from clock and computer analogies, suppose there is a dedicated timing mechanism in the brain – analogous to the central clock in a computer – that form a class of "dedicated models." There are various candidate structures for what may play such a role, with the basal ganglia and cerebellum receiving the most attention (Grondin, 2010). All candidates share the common idea that a special part of the brain plays a dedicated role as a central clock or timer. A weaker requirement is to the existence of multiple dedicated timers for different tasks. While the original idea involves a centralized, and the weaker idea a decentralized, concept of dedication, the common denominator is the concept of a neural structure serving a specific, dedicated role *as* a timing mechanism: a structure selected specifically to function as a timer.

In contrast, “intrinsic models” “propose that timing is an intrinsic computation of most neural circuits, and timing per se emerges from general properties of neurons and the inherent dynamics of neural circuits” (Paton and Buonomano, 2018; p. 688). ROM theory, as clearly illustrated in its AM model, provides a perfect illustration of how temporal representation can emerge naturally in the course of processing time-dependent spatial stimuli. On the ROM model, there is no explicit representation of time – no time markers or time stamps are added to stimuli; rather, temporal properties are an intrinsic feature and product of the ROM dynamics.

There are two objections to intrinsic models to consider, since ROM is an intrinsic model. First, does the unified sense of time we experience despite well-known modality-specific timing variations (e.g., auditory timing is higher resolution than visual timing) not strongly suggest a dedicated timing mechanism? In response, proponents of intrinsic models can point to models like ROM in which a unified sense of time is generated from the unfolding complex coherence among relevant neural ensembles (reentrant oscillatory multiplexing in the ROM case, obviously). Extra glue isn't needed above that already provided by a proper theory of how the neural information flows that realize specious presents are organized.

Second, what about the various structures – especially the cerebellum and basal ganglia – that seem to be implicated in timing task after timing task? There are two key replies to this second objection. (1) intrinsic model theorists hold the view that “areas that are consistently implicated in timing tasks should not be thought of as a central clock, but as areas that are involved in tasks that are inherently temporal in nature…” (ibid.). This shifts the burden to the dedicated model theorist, since it explains the findings without positing a special timing center. (2) Conscious experience (hence the specious present) and timing capacities (with decrement) survive bilateral lesioning of both the cerebellum and the basal ganglia (Laplane et al., 1989; Edelman and Tononi, 2000). Hence, while both structures may be necessary for good timing performance, they are not necessary for the basic temporal content applicable to basic consciousness and basic experience.

There is also an important objection to dedicated models that is worth mentioning. If there were a special faculty dedicated to, and responsible for, timing or providing temporal content to consciousness, then it could malfunction or break (Viera (2016) independently makes a similar argument). This is analogous to how all our special, dedicated faculties (vision, audition, gustation, olfaction, long-term memory consolidation, etc.) can malfunction or break, with the content their integrity requires simply being lost. However, the experience of the specious present isn't ablated by any trauma that doesn't also destroy consciousness *simpliciter*. There aren't any known syndromes that destroy temporality or a sense of temporal passage or immanent time flow while sparing basic consciousness.

This brings us back to a point made at the outset of this dissertation: there is a very special connection between consciousness and temporal experience – as many philosophers, in various ways, have suggested. But if that is the case, then either there can't be a dedicated mechanism for timing or we denude the sense of dedication by equivocating it with the mechanism for conscious experience simpliciter. The upshot is that there are strong reasons for doubting there is a dedicated mechanism for timing in any robust sense, rather than specialized circuits suited to temporal computations at different scales (cf. Lloyd and Arstila, 2014; Paton and Buonomano, 2018; Viera, 2019) or holding that temporal representational content is a necessary part of specious present content (James, 1890; Stern, 1897; Grush, 2005; Buonomano and Maass, 2009; Pelczar, 2010).

7.2.2.4. Relation of ROM to Timing Models

In conclusion, I claim that ROM is a paradigmatic *intrinsic model* of timing as a result of instantiating *state-dependent networks* that generate *population clocks*. Even though ROM is argued for in the context of a time-dependent and not metric-timing model, its mechanistic properties clearly situate it as being relevant to explaining whatever explicit timing content is represented in the specious present.

In this section, the consonance of ROM with aspects of simple, lower-level timing models was noted, and much more importantly the natural harmony with intrinsic SDN and population clock models of timing was highlighted. This is a harmony well illustrated by ROM's AM model, so it, so to speak, speaks for itself. The full ramifications of this fascinating theoretical marriage are an open question.

7.3 ROM and Predictive Processing

As detailed in chapter 5, ROM instantiates a recurrently nested, hierarchical processing structure. This dovetails very nicely with predictive processing models, which have been implicated in explaining apparent motion (Alink et al., 2010; Vetter et al., 2015; Edwards et al., 2017). Moreover, my aforementioned characterization of ROM theory as a non-conceptual resemblance representational theory of the specious present producing narrow content coheres with cutting edge analyses on the commitments of predictive processing models (Hohwy et al., 2016; Wiese and Metzinger, 2017; Williams, 2018).

However, recent extrapolations of predictive processing have attempted to incorporate contrasting models of temporal consciousness. In a recent (2017) paper, Wanja Wiese discusses some problems faced by Grush's TEM and constructs a model, Hierarchical TEM, to remediate its limitations. Similarly, Shawn Gallagher (2017) suggests that predictive processing can augment a Husserlian retentionalist picture. While neither is explicitly attempting to undermine extensionalism, each article is written in support of a conflicting model of immanent temporal experience. For example, Wiese defends the idea that an algorithmically augmented TEM (HiTEM) can do the job:

> This chapter has focused on two features of temporal consciousness, which I called endurance and continuity:
> Continuity = At least sometimes, we experience smooth successions of events (or smooth changes).
> Endurance = At least sometimes, we experience temporally extended events as enduring.
> Rick Grush's trajectory estimation model (TEM), a compelling model of conscious temporal perception, *cannot* account for these features, but I have tried to show that the model can be extended by drawing on features of hierarchical predictive processing models. *Such models posit representations operating at various timescales. As a result, sequences are not just represented as successions of events but as hierarchical wholes* (2017; p.19; my italics)

Since my aim here is not to explain HiTEM or argue in detail against the TEM (covered in chapter 3), I will not dwell on Wiese's arguments. I think it is quite suggestive to note that even someone strongly sympathetic to the TEM finds it phenomenologically insufficient, along argumentative lines laid out by extensionalists years ago. My main point is that Wiese wants to augment the TEM to make it more like ROM.

First, ROM *already is* a model that posits hierarchical activity instantiating representations that operate at various timescales – Buzsaki's (2006) discussion of 1/f neurodynamics is key. There he explains that "time perception does not have a characteristic time scale; it is scale-free. This may be because the brain…uses a complex system of multiple oscillators for its operations with a power (1/f) relationship among them" (p.125).

Second, the phenomenological insufficiency of the TEM claimed by Wiese is recognized by Jakob Hohwy, who claims that from the predictive processing point of view the TEM cannot "account fully for the sense of flow" of the specious present (2016; p. 330). This, however, is not just a problem for the TEM. There is a convergence of opinion that atomist views cannot satisfactorily account for the desiderata extensionalist views are designed to accommodate; that is, explaining the 'continuity', 'endurance', and 'sense of flow' of the specious present are what motivate extensionalist accounts (like ROM) in the first place (Dainton, 2010; Phillips, 2014; Rashbrook-Cooper, 2016; Hohwy, 2016; Weise, 2017).

My suggestion then is that not only is ROM coherent with predictive processing, it is a much more natural fit for predictive processing models generically. I envision Wiese could extend the ROM picture in significant ways. Tellingly, Hohwy et al. (2016) end up with a picture that appears entirely consonant with the neurodynamics of ROM:

> The window of the specious present moves forward because the system expects change and therefore down-regulates the current input. The sense of flow thereby occurs as a property of the internal workings of the hierarchical generative model. This goes beyond just predicting what will happen…and it does not rely on being entrained by the actual changes of the world's hidden causes (p.330).

On ROM, expectation of change is mediated by anticipatory oscillatory dynamics while down-regulation of the current input occurs by phase reset/modulation. ROM *just is* a hierarchical generative model whose internal workings create a sense of time/flow that can track, but does not depend on, external causes (i.e., narrow content).

7.4. Chapter Summary

In this chapter, I have endeavored to point out some very interesting relationships between ROM theory and previously popularized theories to aid their mutual development. SDNs are a class of neural network model that generate temporal representational content in the process of generating other kinds of representational content (location, color, pitch, etc.). Population clocks show how a dynamical systems approach can help explain temporal experience. And predictive processing models highlight the importance of hierarchical emulation-based frameworks for understanding the mind. ROM fits quite naturally with all three such models, arguably instantiating a unified approach to all three. The dissertation, however, does not depend on the defense of these final speculations; they are presented, hopefully, as simply value-added.

7.5. Dissertation Conclusion

In this dissertation, I have defended an extensionalist theory of temporal perception with ROM theory and a congruent differential latency AM model. ROM is an attempt to explain immanent temporal phenomenology: non-conceptual, internalist temporal content. My target has been the brief realm where a unified sense of the present moment is felt.

I have argued that at the short time scales of immanent phenomenology, an extensionalist theory and a ROM theory of vehicular content determination are mutually plausible and supporting.

I have shown a proof of principle of how ROM neurodynamics can realize resemblant temporal non-conceptual contents by giving a detailed extensionalist treatment of apparent motion.

I have responded to multiple arguments against extensionalism and the specious present, two pillars of the ROM account.

Lastly, while it is inevitable that some forms of time consciousness cannot be easily explained on the ROM picture I've developed, I would like to repeat the point that, on the view developed, what determines the scale of temporal representation is the temporal scale of the ROM. That means that spatiotemporally larger realizations of ROM realize specious presents that have greater temporal representational content. I take it as a merit of a ROM view that the density of representational content resembles the spatiotemporal size of the ROM network realized (Edelman, 1987; Newman and Baars, 1993; Edelman and Tononi, 2000; Dehaene and Naccache, 2001; Sporns, 2011).

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