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MODELING TEMPORAL PERCEPTION

BY

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DISSERTATION

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ABSTRACT

We seem to experience a world abounding with events that exhibit dynamic temporal structure; birds flying, children laughing, rain dripping from an eave, melodies unfolding, etc. Seeing objects in motion, hearing and communicating with sound, and feeling oneself move are such common everyday experiences that one is unlikely to question whether humans are capable of perceiving temporal properties and relations. Despite appearing pre-theoretically uncontroversial, there are longstanding and contentious debates concerning the structure of such experience, how temporal perception works, and even whether the perception of change, motion, and succession is possible. The overarching goal of my project is to develop a comprehensive model of temporal perception that does justice to the apparent phenomenology, explains how perception functions to represent temporally structured targets, and generates empirically-informed hypotheses for how such perception is neuro-cognitively realized. I also defend my model against the challenges of anti-realist competitors whom deny the possibility of perceiving temporal relations between non-simultaneous events (e.g., Reid, Chuard, Le Poidevin).

In Chapter 1, I begin with the apparent phenomenology of temporal experience, identifying and lending some plausibility to three claims about the nature and content of temporal experience: i) humans perceive dynamic events that instantiate temporal properties and stand in temporal relations (e.g., change, succession, duration, order), ii) humans perceive events *as present*, and iii) successive events of brief duration can be experienced together *as present* within some finite interval. This approach enables me to outline what models of present experience are supposed to represent and explain. I proceed to sketch one family of models that posit an extended perceptual present to explain how non-simultaneous events can be experienced together as present, called “Extensionalist Models” (e.g., James, Broad, Russell, Dainton). I examine two distinct branches

of extensionalism (Process vs. Content) and proprietary hypotheses linking those models to the real systems they are intended to explain, and challenge the tenability of process extensionalism.

Throughout the dissertation, I advocate for *Content Extensionalism*, the model that holds we perceive the temporal relations between non-simultaneous events in virtue of targeting and representing temporally extended content. I develop the model by pairing it with a theory of mental representation that distinguishes representation from indication, and explains how representations are source-independent isomorphs of their intended targets. In doing so, I demonstrate its comparative advantages over other extensionalist models, provide a straightforward account of claims (i-iii), and equip the model with the resources to defeat an argument that offers two routes to denying the third and most contentious claim—that successive events occurring within a brief interval are experienced together as present. I conclude the chapter by taking a closer look at the “Intentionalist Models” largely based on Edmund Husserl’s seminal work on time consciousness, rehearse some common objections against it, and argue that content extensionalism is a preferable model.

In Chapter 2, I turn my attention to motion perception, arguing that perceptual representations of constant motion are not reducible to mere successions of static perceptions representing what happens at a given time. My position directly opposes temporal atomists (e.g., Chuard, Le Poidevin), whom deny that we perceive motion, claiming that we only perceive what happens at a given time and that putative experiences of motion reduce to a series of static perceptual “snapshots” arranged successively. In the first half of the chapter, I examine and challenge some the motivations for atomism, including its connection to the empiricism of Locke and Reid, and its mereological conception of experience, such that purported experiences of motion supervene on and are reducible to the successive atomic perceptions of which they are composed. In the

second half of chapter, I argue that both the apparent phenomenology and neurocognitive research shift the burden upon atomism to provide a compelling an error theory to explain away our putative perceptions *as of* constant motion and make their anti-realism about extended experiences palatable. I proceed to reconstruct and criticize their standard strategy of appealing to cinematic metaphors to motivate their view that motion perception is entirely reducible to series of static perceptions presented successively. Finally, I draw analogies between Zeno's puzzle of motion and the temporal perception debate, and argue that the atomist explanation of motion experience is analogous to Zeno's failed solution to the original puzzle and that content extensionalism provides a preferred explanation consonant with the Russell-Salmon solution.

In Chapter 3, I continue to combat skepticism about the perception of temporal properties and relations. Le Poidevin (2007) proposes an epistemological puzzle of time perception, from which he derives the claim that the order and duration of events do not causally contribute to our perceptual beliefs about them. Since his view is motivated by a causal truthmaker principle for grounding knowledge, it also holds that perceptual beliefs about temporal features must be caused by the features themselves in order to count as knowledge. Given these theoretical commitments, there is a puzzle concerning how such perceptual beliefs could constitute knowledge of temporal properties. In response to Le Poidevin, I argue for an account according to which order and duration are objects of perception, causally contribute to our perceptual beliefs about them, and such beliefs are capable of counting as knowledge. I conclude by showing that, on my alternative account, the epistemological puzzle dissolves and his own solution to it fails.

In Chapter 4, I specify a target range of temporal phenomena salient to understanding perceptual cognition, and motivate the *multi-scale sampling* (MSS) hypothesis that sensory subsystems sample information at multiple rates, i.e. shorter and longer sampling periods. I argue

that both behavioral and neurophysiological data support the hypothesis that nervous systems process temporal information by sampling stimuli signals at shorter and longer durations, favoring the content extensionalist hypothesis that temporal perception is constituted by multi-scale sampling and integration, over a single-sampling rate hypothesis implied by the atomistic “snapshot” model.

In the second half of Chapter 4, I defend a form of *constructive realism*—the view that scientific theories are best understood as (a) families of models and (b) hypotheses that specify the respects and degrees in which a model represents some real physical system. I conclude the dissertation with a section on philosophy of science, because I engage empirical work throughout the project and employ a model-based approach to theorizing. Furthermore, I suggest that philosophical analysis of the experimental findings may generate new hypotheses and predictions, or offer critical arguments to help rule out the plausibility of particular competing models. To illustrate this interdisciplinary upshot, I briefly make a case for possible philosophical contributions to the fertile domain of temporal processing where there remain many contenders and no consensus on the exact mechanisms that realize temporal perception.

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1. MODELING PRESENT EXPERIENCE

1.1. Present Experience of Dynamic Events

Imagine the following events during a thunderstorm: the wind violently blows tree branches causing them to bend and shake, rain patters a steady rhythm against the windowpane, a lightning strike flashes across the dark sky and a crackling peal of thunder follows seconds later, a dog howls and other neighborhood dogs join in the canine chorus. That a human is able to make observations about events occurring during a storm, in part, on the basis of sensory perception is a banal fact of experience. Instead of being overwhelmed by the flood of manifold information, I am able to select and attend to certain features of my experience as salient and allow others to recede into the phenomenal background. Accordingly, I am able to distinguish, to greater or lesser degrees, the different sources of the complex stimuli from one another, e.g., that the steady pattering originates from the rain hitting the glass pane and the sustained howling issues forth from reverberations in the throat of another creature.

Disagreement over how one's knowledge of the world is constrained by perceptual and conceptual resources, is a perennial problem in epistemology and philosophy of mental representation. How can I observe the visual stimulus *as* lightning, or the auditory stimuli *as* rain pattering, *as* thunder, and *as* canine howling? I must possess concepts (viz., lightning, rain, thunder, canidae) or other representational resources for doing so, or so the standard story goes. The manner in which we acquire these resources varies greatly according to one's preferred theory: empiricists contend that all ideas derive from sensory impressions, association, and reflection, rationalists propose nativism about primitive concepts, and transcendental idealists posit *a priori* first principles of cognition which ground the possibility of all experience.

In the B-edition of the “Transcendental deduction of the pure concepts of understanding,” Kant clearly saw the trilemma (B167-169), “...either the experience makes the concepts possible or these concepts make experience possible....[or the categories] were rather subjective predispositions for thinking implanted in us along with our existence by our author in such a way that their use would agree exactly with the laws of nature along which experience runs...” (2006: 264-265). Of course, Kant thinks both the empiricist horn and rationalist nativism are doomed to failure, and argues that the pure categories are necessary *a priori*, which ground the possibility for acquiring empirical concepts and thereby representing the world. I largely agree, but what follows does not rest on nor presuppose my general agreement with a Kantian inspired representational pluralism, so I will not rehearse his arguments here. Rather, I want to flag that despite drastic differences about the roles and origins of perceptual and conceptual resources, the observations with which I begin do not beg any questions, since everyone can provisionally agree that we undergo temporal experiences and we are able to make such discriminations and observations. My purpose in this initial chapter is to illuminate a particular set of phenomena that lead to diverging models of present experience, and debate the merits of those divergent models.

The manifest world in which we find ourselves is replete with events that exhibit dynamic temporal structure; movement, change, succession, duration, and order are temporal features of our environment. Not only is the world dynamically structured, but we experience it as such. This much I take to be relatively uncontroversial.¹ Furthermore, humans experience *as present* things

¹ Not to say that there are no dissenters. Classically, defenders of Parmenidean monism, like Zeno of Elea, deny that the world is dynamic, as a metaphysical solution to the well-worn paradoxes of change and motion. But, even Zeno recognized that we surely seem to see things moving and changing, but he seeks to explain away the phenomena and argues that the seeming dynamism is unreal. In chapter 2, I discuss Zeno's infamous paradox of the arrow to highlight the mistake involved in denying dynamic properties, and to illustrate some differences in basic models of succession. More recently, 4-dimensionalists claim that the world is a static block and thus not dynamically structured, any purported dynamic properties are reducible to relations obtain between property instantiations at places and times. For instance, Laurie Paul (2011) argues that experiences *as of* dynamic events like motion are

moving, changing, and succeeding one another over finite duration—the dynamic events seem to occur as and when we perceive them. When I see the lightning strike, for example, I perceive the flash of light as present and, after a brief interval, I likewise hear the peal of thunder as present. Even with prior knowledge that the sound event is produced by an electrical discharge and that sound waves travel more slowly than light waves, I do not perceive the thunder *as* past.² In fact, given that sensory information travels at finite speeds and that it takes time for our sensory and cognitive systems to process the inputs, I have little reason to believe that the event I perceive as present is ever strictly simultaneous with my perception of it—there will always be some cognitive latency between stimulus and experience.³ Setting the issue of cognitive latency aside, the research question for this chapter becomes: what does experiencing events *as present* consist in? What is the structure of such experience?

As a starting point, in (§1.2), I identify and lend some plausibility to three substantive claims about the nature and content of temporal experience, which generalize from phenomenological data describing experiences *as of* present dynamic events. This approach allows us to see what models of present experience are supposed to represent and explain. In (§1.3), I provide a sketch of one family of models that posit an extended perceptual present to explain how non-simultaneous events can be experienced together as present, sometimes called “Extensionalist Models,” by

illusory, which bears striking similarities to Zeno's diagnosis, despite being motivated by reductionism instead of monism.

² Cf. Le Poidevin (2007: 78) and Mellor (1998: 16) make the same point that perceiving some event is to perceive it *as* present, even if we believe that the stimulus event is in the near past (or, if you believe the present is a metaphysical fiction).

³ Relativity theory also provides reasons to doubt that there is anything like an absolute objective present; instead there are simply causal relations that obtain between events in the same inertial frame of reference. Dainton (2001), Lockwood (2005), and Maudlin (2007) give accessible and thorough treatments of both the physics of spacetime and metaphysical implications thereof. These issues are beyond the scope of this chapter, which pertains exclusively to ordinary experiences of present temporally-structured stimuli and models of such experience. From this I am not drawing any metaphysical conclusions about the nature of physical spacetime, since I think ordinary experience, on its own, is generally an unreliable guide to the fundamental features of physical spacetime.

examining two distinct branches (Process vs. Content) and the proprietary hypotheses linking those models to the real systems they are intended to explain. In the course of doing so, I offer a *prima facie* argument to favor Content over Process Extensionalist Models.

I proceed, in (§1.4), to consider an argument that offers two routes to denying the third and most contentious claim—that successive events occurring within a brief interval are experienced together as present—and thereby purports to undermine Extensionalist Models committed to that claim. In (§1.5), I rebut the argument, by pairing Content Extensionalism with a theory of mental representation that distinguishes representation from indication, and explains how representations are source-independent isomorphs of their intended targets.⁴ My proposal provides a straightforward account of the phenomenological claims set forth in (§1.2) and disarms the argument against extensionalism. In doing so, I also uncover implicit assumptions of the competing models. This requires taking a closer look, in (§1.6), at the Husserlian “Intentionalist Models” that explain perception of dynamic events by positing that content is modified by tensed modes of orientation. I put pressure on the tenability of intentionalist models and identify features that should be selectively gleaned from them.

1.2. Phenomenological Claims concerning Present Experience

The first phenomenological claim gives a particular answer to the question, “what class of targets is it possible for a system of temporal perception to have?”⁵ By ‘target’ I mean ‘that which perception is directed at,’ i.e. the intentional content of a representation. The class of targets a system of temporal perception can have are those for which it has the resources to represent. Not

⁴ Cf. Cummins & Poirier 2004, Cummins *et al.* 2008, Cummins & Roth 2010

⁵ Answers to this sort of question is what Haugeland (1991, 1998) calls, *objectivity* of representation which is integrally connected to the *intentionality*, i.e. how those targets are fixed by the system. See, Clapin (2002: 119-166) for an insightful exchange primarily between Cummins and Haugeland.

only do we seem to experience temporally structured events (e.g., birds flying, thunder pealing, oneself riding a bicycle), but, if we think such events exist, then such widespread phenomenal seeming provides a strong presumption in favor of the claim that such events are the targets of temporal perception. Events are the objects that such perception is *of* or *about*. In absence of compelling reasons to override this presumption⁶, we should provisionally accept that:

- (i) Systems of temporal perception target dynamic events which instantiate temporal properties and stand in temporal relations.

In other words, a system of temporal perception has temporally structured events as its intended targets. Birds flying, lightning flashing, melodies unfolding, oneself peddling a bike, etc. are events that instantiate temporal properties and parts of which stand in temporal relations, and in virtue of temporal perception we experience such events as having such properties and relations. Since humans seem to undergo experiences of such dynamic events; we cognize, to borrow a phrase from Kant, appearances of that which is changeable elapsing in time.⁷ It follows, that the human cognitive system as a whole somehow has the capacity to detect or experience time – whether in virtue of devoted subsystems or as a consequence of the operation of multiple subsystems or a consequence of the working of the cognitive system as a whole. If so, then dynamic events are the class of possible targets for human temporal experience—*what* such experience is about. These targets are normative for the epistemic accuracy on particular occasions of temporal perception. That is, token perceptions are accurate to the degree to which they represent the temporal structure of their intended dynamic targets.

⁶ In a later chapter, I respond to skepticism about temporal perception, but I will table such worries at present.

⁷ In his discussion of pure schema of substance, Kant (A144/B183) says, “Time itself does not elapse, but the existence of that which is changeable elapses in it.” (2006: 275)

There may be considerable disagreement about *how* humans so perceive, and about the details of the experienced temporal structure. Such disagreement notwithstanding, denying (i) eliminates any initial common ground upon which to debate the merits of the various proposals meant to do justice to the phenomena. Notice, however, that even if someone denies the reality of dynamic events, say, because they are committed to the universe being a static four-dimensional block constituted entirely of static time-slices, she will still admit that the contents of temporal experience are seeming dynamic events (i.e., we have experiences *as of* movement and change)—and offer an error theory for why humans mentally represent dynamic events despite the targets being static time-slices of objects instantiating different properties at different times.⁸ Even on such a revisionary metaphysical picture, (i) need only be modified by exchanging ‘dynamic’ for ‘series of static’ targets. So, for now, we should simply let (i) stand, as is, and let the disagreement between static and dynamic targets play out when I later explicate the models compatible with each.

Moving on, another familiar feature of our ordinary perceptual experiences is that when we undergo them, the objects of experience seem immanently present. Experiences I am currently undergoing are phenomenally distinct from events represented by more remote experiences I have had or will have. I submit that we experience some events *as present*; the experiences I am having now seem to be present *as and when* I am undergoing them. There seems to be a continuous sequences of events I experience *as present*, each of which are present, in turn. When I hear a dog barking I experience the barking *as present*, when I feel a bee stinging I experience the stinging sensation *as present*, when I see a leaf falling I watch its floating descent *as present*, and so on. Each of these present experiences is phenomenally distinguishable from related memories of past

⁸ Recently, Laurie Paul (2011) makes exactly this move; for a similar strategy, compare Philip Chuard (2011).

dog barks, bee stings, and leaf falls, since in memory none of the events are represented *as* present. These observations generalize to a second claim about temporal experience:

(ii) Humans perceive events *as present*.

To put it in a slightly different way, undergoing experiences of dynamic events occurs within the “conscious Now” of the perceiver.⁹ For instance, when I am perceiving the lightning flash, the bright flash is experienced as present to me—as happening now—in contrast to the phenomenal quality of the event having occurred at some earlier time, when I later remember the lightning flash. This suggests that there is something that it is like to experience an event as it occurs, and conscious “nowness” distinguishes the objects of present experiences from remembrances of events past and imaginings of future events to come. When I bite into an apple, I taste the sweetness and feel the crisp texture on my pallet at *that* time; there is a nowness to my experiencing the phenomenal properties of sweetness and crispness.¹⁰

Some might confuse this notion of nowness as a substantive metaphysical property of events in the world. One might immediately balk at positing some secondary quality of phenomenal properties, or ascribing some irreducible monadic property of nowness to events themselves.¹¹ Perhaps, rightly so, since it seems to imply both that experiences have phenomenal properties and

⁹ The phrase ‘conscious Now’ is used by psychologist Eva Ruhbau to indicate the interval of present perception; she argues that the conscious Now is “of the duration of approximately 3 seconds” (1995: 168). Here I am using her phrase merely to identify the present perspective, without making any claims about the duration of the Now.

¹⁰ If you are a friend of qualia, then you can think of this experience as having a sweetness-now quale and a crispness-now quale. I prefer to avoid such commitments, and “Quine” qualia (see Dennett 1988).

¹¹ Paul (2011: 335) attributes this view to the so-called “antireductionist” tense realists, whom hold that tense is an intrinsic feature of the world and use our experience *as of* nowness to infer that events have such a property (cf. Hare 2010). I have no interest in making such an argument for tense realism, which is why I take (ii) to be a phenomenological claim about our temporal orientation to events as and when we experience them, but is ontologically noncommittal. It may turn out, however, that some form of *perspectival realism* is unavoidable.

that the instantiation of those properties (while someone is undergoing an experience) has a further quality in virtue of presently occurring. I suggest that this balking is a bit premature.

To be charitable, I think (ii) can be given a reasonable gloss, without buying too many commitments about a particular metaphysics of mind. When I am listening to a recording of Charlie Parker riffing bebop on the saxophone, for example, there is a real sense in which I hear his meandering chromatic progression occurring *now*, as and when I listen to the record play. I do not confuse the nowness of my experience for a property of the recorded performance itself (I realize the original event took place in the 1940s); rather, my listening to the recording is taking place now and the auditory stimuli produced by the stereo speakers are causally influencing my present experience of the musical sound event.¹² This description of my experience does not commit me to some irreducible nowness in the world, rather it just recognizes that one undergoes experiences within a present frame of temporal reference.

On this demystification, (ii) only implies that some contents of perception are perspectival and sensitive to the context of occurrence. This should come as no surprise at all. Most parties can accept this minimal claim of phenomenal presence whether one thinks that phenomenal properties are intrinsic nonintentional features of experiences (i.e. qualia¹³) or, extrinsic intended features of targets represented in experience (i.e. representational content¹⁴). Alternatively, one can posit that phenomenal properties are *impure representational properties*, which an experience instantiates in virtue of representing an intentional content in a certain manner.¹⁵ Likewise, metaphysicians of

¹² Elsewhere in Ch. 3, (Bowen 2013), I endorse a view that sounds are events in space-time. On the sound as event view, playing a recording produces a new sound event, an ancestor of the original recorded performance. It is this ancestor which causes the present experience.

¹³ See Horgan and Tienson (2002), McGinn (1988), Siewart (1998), Chalmers (2004).

¹⁴ See, e.g., Harman (1990), Tye (1995, 2000, 2003, 2013), Carruthers (2000), Dretske (1995), Lycan (1996).

¹⁵ Julian Kiverstein (2010: 158) explicitly endorses this route, and he attributes the terminological distinction between ‘impure’ and ‘pure’ representational properties (i.e. those with intentional content) to Chalmers (2004) and also defended by Crane (2009).

various stripes can and do admit that we have experiences *as of* present events, whether or not one holds that tense is an irreducible property of events. So, the phenomenal presence of experience asserted by (ii) should also be endorsed, at least, on the ontologically innocent reading I suggest.

A third claim about temporal experience can be illustrated by the thunderstorm example: although a peal of thunder has a relatively brief duration, I seem to hear the sound event in a single present unified experience while also discerning both that the event has a very brief duration and that the sound has earlier and later parts (say, a sharp crack followed by a rolling boom). This phenomenological datum generalizes to:

- (iii) Successive events of brief duration can be experienced together *as* present within some finite interval.

Michael Lockwood characterizes a somewhat stronger version of this third claim as follows:

It seems to be a brute fact about experience that events which are contained within a sufficiently small interval can be experienced as a group, encompassed within a single phenomenal perspective, without thereby being experienced as simultaneous. (Lockwood 1989: 263)

Lockwood is asserting that relatively rapid non-simultaneous events are experienced together as phenomenally present, over some brief duration. He is also claiming that this is a brute fact, not further analyzable in other terms, on which (iii) is agnostic. The basic idea is that the conscious first-person perspective spans a ‘sufficiently small interval,’ in which sequences of brief events can be experienced as and when they seem to occur. Combining (ii) and (iii) entails that some events are experienced together as phenomenally present, and the scope of one's present perspective can encompass non-simultaneous events. The conscious now of the perceiver is not an

instant, but an interval. Claim (iii) implies that present experience encompasses non-simultaneous events of some brief duration. Also, if one takes it to be a brute fact along with Lockwood, then dynamic experience is constituted by representations of non-simultaneous events grouped within ‘sufficiently small’ extended intervals. To use a figurative metaphor, we do not drink in the dynamic world one drop at a time, rather we drink it in by gulps containing collective drops. The resulting view informs one family of models representing how temporal experience is structured, by positing an extended present to explain how the perceptual experience of dynamic events within a single phenomenal perspective is possible—*Extensionalist Models*.¹⁶ I will further explicate the common features of such models below (§1.3) and how branches of the family differ from one another, ultimately defending a version of *Content Extensionalism*. After articulating the features of extensionalism, I turn to an argument that denies (iii) and with it extensionalism.

1.3. Extensionalist Models

Extensionalist models posit an extended present to explain how non-simultaneous events can be experienced together as present. Typically, the term of art ‘specious present’ refers to the brief extended interval in which the contents of experience are present to the perceiver; as William James famously describes it, “the prototype of all conceived times is the specious present, the short duration of which we are immediately and incessantly sensible” (1890: 610). ‘Specious,’ in this context, simply means ‘appearing to be experienced’, i.e. it is the duration encompassing what

¹⁶ I follow Dainton (2008: 363) in adopting the designation ‘extensionalism’ for these views of temporal experience. Dainton’s (2000, 2001, 2003, 2008) defends his “Simple Overlap Model” which is a type of process extensionalism, other defenders of extensionalism include James (1890), Stern (1897), Russell (1915, 1927), Foster (1979), Sprigge (1983), and more recently, Strawson (2009), Soteriou (2007, 2011), Hoerl (2009, 2013). Heidegger’s ‘ecstatic-horizonal’ model (1988: 261-273) is a special case, because he endorses a form of extensionalism about represented time, when he posits ‘spannedness’ [*Gespanntheit*] as an intrinsic character of ‘structural moments of expressed time,’ but defends a form of tensed Husserlian intentionalism when he analyses the basic constitution of temporality “...as the original unity of future, past, and present, is *ecstatically-horizonal* intrinsically” (1988: 267).

seems to be present to a subject at a given moment, where ‘moment’ refers to a non-zero interval—an extended present. The concept, however, is employed by different philosophers and psychologists in at least the following four ways: to gesture at a general idea regarding the temporal extension of subjective experience, to denote the duration of external events experienced as present, to denote the non-zero duration of present experience itself, and to identify a particular branch of theories which propose similar explanations of temporal phenomena in perceptual experience (e.g., succession, change, persistence, simultaneity, duration).¹⁷ Instead of derailing the discussion into an exercise in conceptual house-keeping, I prefer to eschew the term ‘specious present’ and discuss the details of extensionalist models.¹⁸ These models come in two branching sub-types: *Process Extensionalism* and *Content Extensionalism*.¹⁹

1.3.1. Process Extensionalism

Beginning with the first sub-type, here is an official gloss:

Process Extensionalism: Experience of a temporally extended event consists in an extended experiential processes with intrinsic temporal structure: (a) composed of temporally contiguous experiences of temporal parts of the events, (b) in virtue of being an extended process, an experience represents the temporal structure of dynamic events occurring within the same brief interval that the experience itself seems to take up.

¹⁷Cf. Clay (1882), James (1890), Broad (1923), Boring (1949), Myers (1971), Pöppel (1978, 1988) Ruhnau (1995), Varela (1999), Dainton (2000, 2008), Kelly (2005b), Lockwood (1989, 2005), Soteriou (2007), Hoerl (2009) and Phillips (2010). See also Gallagher (1998: 26-31) for a discussion of the terminological and philosophical perplexities of the specious present.

¹⁸ The term ‘specious present’ carries different connotations for different theorists, from fairly benign to ontologically weighty. Since it might do more harm than good, and distract from the main issue of modeling present experience, I prefer to avoid the loaded language.

¹⁹ Cf. Chuard (2011) for an extended critique of both views, which he calls “State Temporal Extension” and “Content Temporal Extension,” respectively. I elect to use ‘process’ instead of ‘state,’ since I think it better captures what defenders like Dainton (2000, 2008) and Phillips (2008, 2011) are claiming. Geoff Lee (2014) also calls them “Experiential Process Views,” which he contrasts with his favored “Extended Atomic View”—a version of Content Extensionalism on my account. The lack of uniformity in labels for models is a bit confusing in this literature, so I adopt familiar labels where possible, and remain consistent in my attributions throughout.

When, for example, I see a bird's motion in flight, my experience is composed of disjoint but contiguous experiences of brief segments of the bird's flight.²⁰ Likewise, when I listen to Bird Parker's chromatic progression on the saxophone, my experience of the longer melody is composed of briefer experiences of parts of the progression. Figure 1, depicts temporal experience on the basic Process Extensionalist Model:

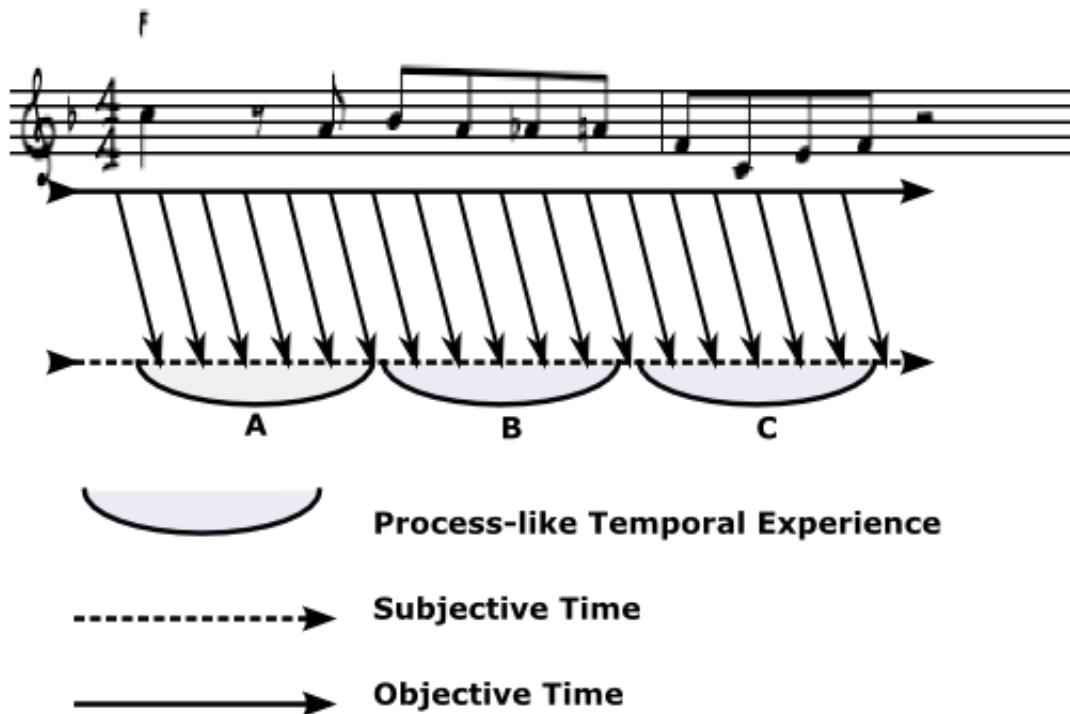


Figure 1: *Process Extensionalist Model:* A, B, C represent individual experiences that compose the longer ongoing experience of the melody.

The model posits process-like experiences (A, B, C) that mirror the temporal structure of the events occurring within the interval of each experience. The downward arrows in the figure represent the hypothesized temporal synchrony between the timing of the target and the timing of the

²⁰ One might reasonably inquire, “how finely or coarsely are these constituent experiences individuated? Do experiences have proper temporal parts? Or, are experiences gunky?” At this point, we can safely set that worry to one side, and take it up later when event segmentation is a more central concern.

experience. A primary motivation for conceiving of process-like experiences is to accommodate the intuition that a dynamic experience directly reflects the temporal structure of its dynamic target. This intuition is something about which Ian Phillips claims we cannot be systematically in error, “when we reflect upon the nature of our experience, we come to appreciate that the apparent temporal structure of experience maps the apparent temporal structure of the world experienced” (2008: 197). When I see the bird flying it seems as though my ongoing visual experience tracks its spatio-temporal path, presenting the temporal properties and relations of events perceived in virtue of being in synchrony with them. As I listen to a melody, my experience seems to be carried along by the tempo of the music. According to process models, the temporal structure of my experiences correspond to the temporal structure of the events experienced. Geoff Lee (2014) argues that this intuitive hypothesis, what he calls “Mirroring,” is the essential feature of process models, and ultimately what he takes to be their Achilles Heel. Lee offers three possible degrees of Mirroring that a Process Model might endorse:

Mirroring comes in different strengths. On *Metrical Mirroring*, the ordering *and* duration relations between the temporal parts of a process-experience match those of the apparent perceived scene. So for example, an experience of a 1 second gap between two sounds is mirrored by a 1 second gap between the experiences of the sounds themselves. *Topological Mirroring* is weaker, only requiring mirroring at the level of temporal order, not duration. *Structural Mirroring* is even weaker, only requiring that distinct temporal stages of the perceived scene are presented by distinct temporal stages of experience. (2014: 8)

There is a certain simplicity in the process model, since it has a short and simple story to tell about how a system targets dynamic events that instantiate temporal properties and stand in temporal relations [claim (i) above]—by mirroring them in the process of perceptual experience. We can give a general definition of the hypothesis, as follows:

MIRRORING: For any temporal property T and for any experience ϕ , if a phenomenally present event E is experienced, and E seems to instantiate T , then ϕ itself instantiates T .²¹

If it seems as though the thunder rumbles for 4s, then my experience of the thunder has a duration of 4s. If my experience seems to have a particular temporal structure, then it does have that structure. MIRRORING is thus a kind of incorrigibility thesis about temporal experience. The hypothesis entails that experiences inherit their temporal structure from the apparent objects of experience.²² In the example there are at least three times in question: a) the actual timing of the thunder roll, b) the experienced timing of the thunder roll (viz. 4s), and c) the timing of the mental process that instantiates the experience. The inheritance of structure implied by MIRRORING can be understood in two distinct ways: either the objects of experience are mental entities like sense data (i.e. b inherits its structure from c) or the objects of experience are events out in the world (i.e. b inherits its structure from a).

On the first route, the apparent objects of experience are mind-dependent, easily accommodating cases where the mental thunder roll does not correspond to any electrical discharge in the atmosphere, since the experienced timing is inherited from the timing of the mental event. Hence it seems innocuous to claim that the temporal structure of an experience mirrors that of the mental event, even in cases where the event is a hallucination. Nevertheless, this merely pushes

²¹ Ian Phillips explicitly endorses this sort of hypothesis, “for any temporal property apparently presented in experience, our experience itself possesses that temporal property.” (2014: 694)

²² Alternatively, one might claim, following Leibniz, that God programs a *pre-established harmony* between mental events and bodily events in the world, and thus MIRRORING is a function of God’s will such that when the lightning causes a thunder clap, my mind mirrors the event out in the world. Likewise, Malebranche’s occasionalism is consistent with MIRRORING, but with the important difference that God is the only efficient cause in a Malebranchian universe and thus God causes my experience to be occasioned by the thunder clap, God also coordinates the sound waves being occasioned by a lightning discharge which God causes to result from the static energy, etc. None of the contemporary parties to this debate concerning temporal perception actively endorse either of these 17th century rationalist strategies, so I think this footnote suffices to flag the possibility without further engaging it as a serious contender.

the problem back for ordinary cases where there is an external thunder event, requiring further explanation of the relationship between the sense data structure and the external event, the relationship in virtue of which sense data represents the structure that the experience so inherits. If the experience inherits its temporal structure from sense data, and in some cases the experienced timing (b) corresponds to the actual timing (a), then there must be some explanation of how the sense data can accurately represent the temporal structure of the event out in the world. Either sense data can represent worldly events without another inheritance principle, making MIRRORING an unnecessary complication in the process extensionalist explanation of how we experience dynamic targets since the relationship between the target and the sense data will do the analytical heavy lifting, or else sense data inherit their structure from the worldly events they mirror which collapses into a version of the second route.

Additionally, on the first route, MIRRORING makes a troubling claim of correspondence between temporal structures (b) and (c). The apparent timing of the event and the timing of the experience itself are claimed to mirror each other, instantiating the same temporal properties and relations. On the face of it, MIRRORING appears to violate the *transparency* of perceptual experience. A widely held view is that perceptual experience is *transparent*, meaning that the content of perceptual experience represents qualities of the states of affairs experienced, rather than intrinsic qualities of the experiencing.²³ When I hear the booming thunder roll for 4s, according to transparency, my perceptual experience represents properties of the thunder event, including its pitch and duration, not the properties of my auditory system processing the information transmitted by the sound event. Yet, this is precisely what is being suggested on the mind-dependent interpretation of MIRRORING, if my experience of the temporal structure of the

²³ See Harman (1990), Dretske (1995), and especially Tye (2002) for defense of the transparency of perceptual representation.

thunder roll inherits its structure from the mental process instantiating that experience. When I see the spatial dimensions of a room, I do not judge that my visual experience shares those dimensions, it merely represents them. Smelling a skunky odor I don't judge that my experience is itself skunky, or feeling the tackiness of drying paint I don't judge my experience to be tacky. If I made any of those judgments, then I would be systematically in error as to which properties are represented in perception and what those properties represent. By claiming that a temporal experience mirrors the temporal structure of that which is experienced, process extensionalism commits an implicit content/vehicle confusion.²⁴ “The message is: Don't confuse the representation of time with the time of representing; don't confuse the representation of sameness with the sameness of representing; and so on. That is, don't suppose the *type* of contents must project onto their subpersonal vehicles, or vice versa” (Hurley 1998b: 42). Process extensionalism conflates the content of an experience with the vehicle instantiating the perceptual representation, and thereby has the burden of defending the idea that temporal properties are unique in that they do project onto their subpersonal vehicles or vice versa, via MIRRORING.

Tough questions remain concerning what mechanisms realize this process and whether or not some version of the MIRRORING is even plausible on a developed theory of mental representation.²⁵ The former question is empirical, and can be set aside for now (see Ch.4). The latter question about representation is more pressing and raises explanatory problems for process models, which require some attention.

²⁴ Process extensionalism seems to conflate the content and the vehicle of the experience, a critique advanced against process models by Dennett & Kinsbourne (1992) and Grush (2007).

²⁵ To account for functional mechanism, process models might appeal to dynamic oscillators and find a natural ally with Dynamic Systems Models (e.g., Van Gelder 1998, 1999; Van Gelder & Port (eds.) 1995), that challenge representational accounts of cognition, and thereby avoid some of the problems facing the Process Extensionalist Model, but also inheriting some of the problems facing anti-representationalism. Cf. Clark (1998)

On the second route, experiences inherit their temporal structure from the events in the world being perceived, but this generates a problem for cases of hallucinated targets since there is nothing from which to inherit the structure. Given that MIRRORING is a property inheritance principle, it implies that temporal experiences are source dependent, where an experience presents a dynamic event with specific temporal properties only in virtue of instantiating the same properties as and when the event unfolds. In a sense, this explanation lets time be its own model.²⁶ If so, then the process cannot mirror an event's temporal structure in absence of the constituent temporal phases of the event. But, in some cases, we do seem to experience dynamic events in their absence. Temporal illusions and musical hallucinations are cases where one experiences a dynamic event instantiating temporal properties and relations, but when the target has a different temporal structure (i.e. temporal illusion) or is entirely absent (i.e. hallucination).

The process extensionalist has some wiggle room with illusions, since an experience only instantiates the apparent temporal properties of the events experienced.²⁷ Sometimes one's experience seems to slow down relative to the world, for instance, when being thrown from one's bicycle, a psychological effect known as *subjective time dilation*. Since the events of hurtling over one's handlebars seem to be stretched out in time, so too is the experience thereof on the process model. The experiential process mirrors the apparent temporal structure, in such cases, but its apparent structure is still source dependent, since there are dynamic events and although the subjective duration of them is dilated, the order is accurately reflected (e.g. one hurtles over the handlebars before hitting the ground). So understood, cases of subjective time dilation undermine

²⁶ In artificial intelligence, anti-representationalists like Rodney Brooks (1991) have designed robots that can carry out various tasks without computing any internal models, but by 'letting the world be its own model.'

²⁷ This is especially true for Dainton (2000) who endorses a Lockean theory of perception, he calls 'projectivism.' So, his process model only requires that the mirrored properties are secondary qualities of phenomenal objects. Foster (1982) defends a form of Idealism that is also primarily concerned with the temporality intrinsic to phenomenal contents.

metrical mirroring, since the experience does not mirror the duration of the event. This leaves only the weaker topological and structural mirroring theses available to the process extensionalist. Potentially more damaging examples are those where the dynamic target is absent altogether.

What structure is the mirror process reflecting when I experience a catchy tune playing in my head or, worse, an annoying commercial jingle? Such an experience is sometimes called an ‘earworm’ or ‘brainworm.’²⁸ Although this is not a case of perception, the rather common phenomenon of experiencing a melody repeat in one's head does seem to be an experience, the content of which represents the temporal structure of the tune (probably more so than its tone and pitch), in the absence of the target. Some individuals also undergo intense musical hallucinations, in which they “hear” music playing out in the world when there is none at all—a seeming perceptual experience. For patients whom experience this type of hallucination, neurologist Oliver Sacks reports, “this sort of instant reproduction has some resemblance to our reaction to catchy tunes, but the experience for someone with musical hallucinations is not mere imagery, but often physically loud, as-if-heard ‘actual’ music” (2007: 73). Thus, a full-fledged musical hallucination is a temporal experience, for which there is no dynamic target present.

How can the process model account for such experiences with MIRRORING? Does the brainworm or musical hallucination consist in a process that mirrors a simulated auditory event? Perhaps, the process extensionalist can appeal to processes inheriting the apparent temporal properties from earlier processes, in order to give an account of where the apparent temporal structure comes from. For instance, a previous extended process of my experiencing the song,

²⁸ Cf. Oliver Sacks (2007: 41-48) chapter of *Musicophilia* dedicated to brainworms, i.e. the phenomenon of “hearing” a repetitious musical phrase or melody in one's mind. Metaphysician's Warning: Do not confuse this use of the term for a metaphysical implication of 4-dimensionalism in which a brain persists in virtue of have different temporal parts at different times, where brain A at t1 is numerically identical to brain B at t2 iff A and B are timeslices of the same 4D brainworm.

“You Can’t Always Get What You Want,” is encoded as an auditory memory trace, and when I later experience the melody repeat in my mind, the brainworm process inherits its temporal structure from the initial auditory process via the memory trace, or so the explanation goes. A response along these lines generates new puzzles concerning how the temporal signature of the process is stored and how this re-process experience sequence is initiated to generate the hallucination.

This suggestion is also ill-suited to explain how someone might hallucinate entirely novel musical sequences—a condition apocryphally attributed to Shostakovich as a result of a piece of metal shrapnel from the siege of Leningrad being lodged in the composer’s auditory cortex.²⁹ He reportedly found inspiration for his compositions in these novel musical hallucinations. Given that these are not simply memory experiences of some previous experience, such phenomena seem utterly mysterious for MIRRORING process models of temporal experience. Or else, it forces a retreat to phenomenal idealism, where the apparent phenomenal objects of experience are all that exist. A move welcomed by process theorists like Foster (1982) with independent commitments to Berkeleyan idealism, but one that should be met with resistance from anyone that takes a realist reading of the dynamic targets I motivate in (i). At the very least, cases of this sort should put pressure on MIRRORING and its implicit source dependency.

There are possible ways for the process extensionalist to respond to these challenges. For one, a process model might reject a representational account of perception, and opt instead for what is sometimes called a ‘relational view’ of perception.³⁰ According to the relational view, perception

²⁹ Donal Henahan (1983) makes this claim about Shostakovich, “Shostakovich, however, was reluctant to have the metal removed and no wonder: Since the fragment had been there, he said, each time he leaned his head to one side he could hear music. His head was filled with melodies—different each time—which he made use of when composing. Moving his head back level immediately stopped the music.” (as cited in Sacks 2007: 72f)

³⁰ Cf. Hoerl (2013: 6-8) for discussion of the view; proponents include Campbell (2002, 2009), Brewer (2004), Soteriou (2007, 2011).

is a distinctive relation of awareness or acquaintance that obtains between the subject and the objects in the world. As John Campbell expresses it, “it is not that the brain is constructing a conscious inner representation whose intrinsic character is independent of the environment. It is, rather, that there is a kind of complex adjustment that the brain has to undergo, in each context, in order that you can be visually related to the things around you” (2002: 119). This ‘complex adjustment’ explanation is a natural partner for the process model, since mirroring experiences supposedly play precisely this role in our perception of temporal properties and relations. I am not advocating for this relational move, I am merely suggesting that the process model pairs well with a rejection of representational accounts of perception, in order to resist objections based on standard theories of mental representation. Anti-representationalism might be a cost too steep for what process models provide in explanatory value. At this point, it is only important to possess a working idea of how the Process Extensionalist model accommodates claims (i)-(iii) with which we began, and some of its implications for how temporal perception is supposed to work. Now let us turn to the second branch of extensionalism.

1.3.2. Content Extensionalism

Unlike process models, Content Extensionalist models do not posit an extended process that inherits the temporal properties of target events experienced. Instead, content extensionalism claims that the content of an experience *as present* represents events that occur in a brief temporally structured interval, i.e. a *temporal field of content*.

Content Extensionalism: Experience of a temporally extended event consists in a perceptual representation encompassing a temporal field of content: (a) content of an experience *as present* represents successive events occurring over a brief temporally

structured interval, (b) the realizer of the experience (state or process) need not have the same temporal structure as the successive events represented.

When I listen to a melody, I experience parts of the sound event together as present. This does not imply that the process or state realizing my auditory experience has the temporal structure of the melody, since a vehicle only carries the information or representation. On this model, the perceptual system targets dynamic events instantiating temporal properties in virtue of representing temporally extended phases of the events and the temporal relations that obtain between their parts. A temporal field is the scope an experience encompasses, an extended window or interval within which temporally structured events can be experienced together. Figure 2, below, depicts the basic sketch of a Content Extensionalist Model:³¹

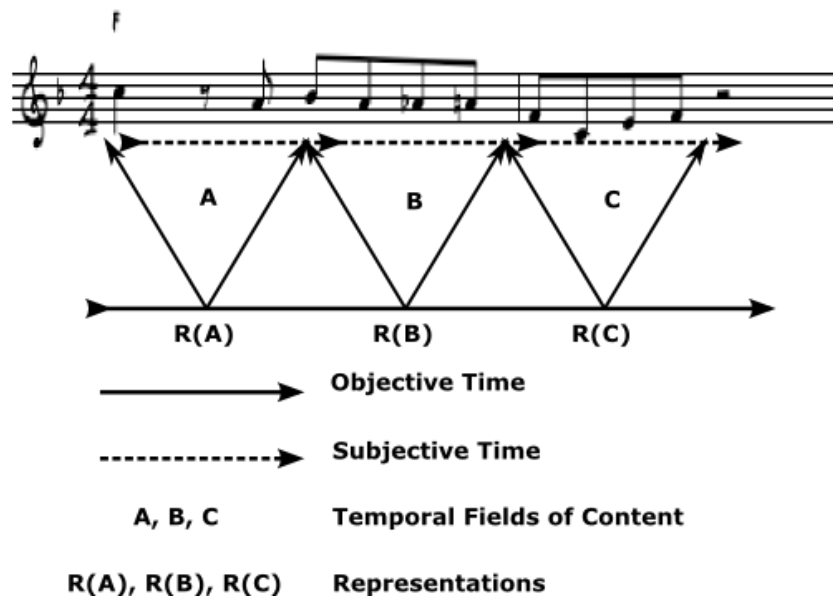


Figure 2: *Content Extensionalist Model*

³¹ Proponents of models in this family include Broad (1923, 1925), Tye (2003: 85-92), Grush (2005), Bowen (2013) each with their own distinguishing features. Lee (2014) also defends a version of this model under the label, “The Atomic View,” where on his view temporal experience involve what he calls ‘local holisms,’ which correspond roughly to the temporally extended fields of content on my articulation of Content Extensionalism.

The model posits temporally extended fields, i.e. the interval of an experience as present, and some mechanism for representing the content in those fields in order to explain how successive events can be experienced together as present. In Figure 2, for example, the beamed quadruplet of eighth notes are within the scope of field B, and thus the cognitive system fixes the target quadruplet and deploys $R(B)$ to represent its temporal structure including its brief duration and the order of occurrence within the field (i.e., I hear the B quaver as occurring before the A, the A as occurring before the A flat, and the A flat as occurring before the A natural). According to this model, temporal experience is representational. I experience successive events occurring within a brief interval as present in virtue of representing the temporal properties instantiated by and relations that obtain between the events. On this way of understanding content extensionalism, dynamic targets (e.g., musical phrases) are fixed by the representational function of some mechanism within the cognitive system which deploys $R(F)$ to represent in experience the temporal structure of events occurring within some present field of content, F .³²

Since content extensionalism can be elaborated in several different ways, there are a few additional points about the model that bear further clarification. First, one might worry that the time of representing is an instantaneous state of the system, on a content extensionalist model. While some versions of the model might endorse this instantaneity, as Broad's (1925) version seems to, other versions accommodate the possibility that the physical process realizing the representation is itself extended in time, including Broad's earlier (1923) model that posits 'momentary acts of sensing' which are realized over a finite interval. Such models are importantly different from process models, because the temporal properties of the realizing process (e.g., the

³² In a more general theory of mental representation, Cummins (1996) dubs such mechanisms, 'intenders', whose function it is to represent a particular class of targets.

firing rates of neuronal cell assemblies) are not the same as those represented in the temporal field of content. To put it another way, the vehicle of the representational content may have temporal structure determined by its physical realization in a distributed neural process, but the vehicle's temporal structure is not the same temporal structure as the content it carries. Content extensionalism does not confuse the temporal properties represented in the temporal field of content with the temporal properties of the vehicle that carries that content, i.e. content extensionalism does not commit a content/vehicle confusion.³³ This clarification underscores one significant way in which content models differ from process models.

Second, the diagonal lines in Figure 2 delimit the scope of the temporal fields, and those that slope to the left appear to extend the field into the future. How can R(A) represent an eighth note that has not yet been played?³⁴ If real-time perceptual representation involves some inductive extrapolation from observed stimuli, in order to target ongoing dynamic events, then some of the temporal field of content is a projective construction. Although this “forward-looking” feature is not essential to the model, I drafted the diagram to accommodate it, since some versions of content extensionalism hypothesize that temporal perception requires predictive interpretation.³⁵ For instance, one such model posits a mechanism that realizes a trajectory estimation function, mapping states of the process onto successor states. This enables a cognitive system to predict future transformations of represented events by filtering the noise from observed signals and exploiting a prediction-correction cycle to generate statistically optimal state estimations (Grush, 2005a: S211).³⁶ Content extensionalism paired with a trajectory-estimation hypothesis

³³ For further discussions of the content/vehicle distinction cf. Dennett (1991), Dennett & Kinsbourne (1992), Hurley (1998a, 1998b), Millikan (1993), Grush (2005b).

³⁴ See Kelly (2005b) for a critique of extensionalist views that have a forward-looking component.

³⁵ Cf. Dennett & Kinsbourne (1992), Rao et al. (2001), and Grush (2005a).

³⁶ In particular, Grush (2005a) develops his trajectory estimation model based on a Kalman filter (cf. Kalman 1960), which is an information processing algorithm for filtering noise from signal data to produce estimates of future states of domain, wherein Grush assumes, for the sake of computation, that the modeled domain is a driven Gauss-

accommodates the possibility that a system can represent a temporal field of content that incorporates a projective estimate constituting its leading edge.

Other versions of content extensionalism specify that a temporal field only extends into the near past. In fact, Broad makes the “backward-looking” constraint on his model explicit when he says, “it is certain that what can be sensed at any moment stretches a little way back behind that moment.” (1923: 348) and “to sense what has not yet become, would be literally to sense *nothing*” (1923: 358).³⁷ To accommodate Broad’s constraint in the figure, the left-sloping diagonals can be made perpendicular to the representation times.

Notice, however, that Broad’s way of putting the point in terms of sensing and not being able to sense what has not yet become, construes perception as a passive process of receiving information from the senses as events happen. Broad’s view implies a causal theory of content that identifies targets by correlating sense data tokens with detections of distal properties.³⁸ Such a theory reduces representation to correctly processing detector signals, since it holds that the content of a token temporal experience of succession $R(F)$ is its dynamic target under conditions of correct application, e.g. when the temporal relations of succession within F actually obtain. This conflates the content of the representation with the content of its correct applications, simply mapping temporal experiences under the right conditions onto appropriate temporally structured events. For this reason, Broad’s version of content extensionalism seems to be plagued by a similar problem as process models, since there is an implicit source dependency between a series of *sensa* represented within a momentary sensible field, and temporal properties of events causing the

Markov process (e.g. a ship at sea whose states (position, velocity) at $t+1$ are determined by its position and velocity at t , ‘noise’ like winds and currents, and predictable driving forces like the engine and rudder).

³⁷ Of course, this follows straightaway from Broad’s metaphysical position; he defends a Growing Block Universe theory in which the four-dimensional universe grows as time advances. So, it would be impossible to perceive the future, if one were to also think that perception is causally source-dependent (like Broad’s sense data theory).

³⁸ Contemporary versions of causal theories of content include Stampe (1977), Fodor (1987), Dretske (1981); for extended criticism see Cummins (1996: Ch. 5), Cummins & Poirier (2004), Paul Churchland (2007).

representation to be tokened on that occasion. I raise this issue as a point of caution, and in order to contrast Broad's version with other versions of content extensionalism which are not married to a causal theory of content.

Let us consider an alternative version of content extensionalism. On this view, representation is an isomorphism between the content and the actual or possible states of affairs targeted, i.e. a relation-preserving mapping between the content and its target (cf. Cummins, 1996; Waskan 2006: 94-102). If temporal experiences are representations, as content extensionalism has it, then their content is grounded in the relational properties instantiated, not in the causal relations they bear to dynamic events in the world. A target is normative for judging the accuracy of a representation deployed on a particular occasion, but a representation's content is not fixed by its causal relation to the target on any particular occasion, it is fixed by the actual or possible states of affairs represented. As Paul Churchland (2007: 156) points out, in a relevant discussion of maps, "it is the existence of an abstract, relation-preserving projective mapping, from some external domain to that map, that makes it a good or an accurate portrayal of that external domain. Causal connections enter the picture only if, and only when, the map is finally put to some use or other." For example, Jesse has an accurate street map of downtown Chicago just in case there is a relation-preserving mapping between the city's streets and the representation. If Jesse mistakenly tries to use the map to navigate the streets of Milwaukee, then she is deploying the map incorrectly—the map still represents Chicago, and has the relations between Chicago streets as its content, but is being misapplied to the wrong external domain. So, a representation's content is not causally determined by a particular occasion of its correct or incorrect use.

For example, Figure 2 is a representation of how a possible system perceives successive events together as present, by positing temporal fields that delimit intended targets fixed by

representational functions. The figure does not represent the actual temporal structure of a particular sound experience, which has been partially encoded in a spatial form, since the figure is a static graphic not a temporally evolving model. The temporal structure is recoverable from the representation, given that the time signature and the musical notation encode features of musical passage in F major, such that a musician could play it—their performance serving as a projective relation-preserving mapping—and thereby undergo the temporal experience. If so, the notation represents the music's structure and the musician's subsequent auditory experience represents the sound event generated by her performance, but the experience does not represent the notation. So, representation is intransitive. This also entails that, “representations, because their content is grounded in their structure, do allow for portability of representation” (Cummins & Roth 2010: 179). The portability, i.e. source independence, of representations has useful implications for the problem broached earlier concerning temporal illusions and hallucinations.

We are now in a position to see that content extensionalism, with representational content, has a much easier time accounting for seeming perceptions of absent targets. In contrast to mirror processes, source independent representations are better suited to explain brainworm and hallucination phenomena. After all, an accurate representation is an isomorph of its target, by definition, and a representation is portable, since it can be deployed in the absence of its target. This view of mental representation also provides a reasonable explanation of the Shostakovich case, since representational schemes are in the business of structurally transforming tokens of semantically individuated types.³⁹ So, Shostakovich “mentally composes” in virtue of mechanisms in his auditory cortex manipulating musical tokens and thereby generating novel representations,

³⁹ Cf. Cummins & Poirer (2004: 21-40)

which he then transforms into external compositions and physical music—the dynamic targets his hallucinations represent, prior to their physical realization in sound waves.

This move, while consistent with content extensionalist models, undermines the motivating intuition of process models, since the vehicle of a representation (e.g. spike trains across a neural assembly) need not mirror the properties of the target at all. All the worse for process models. Adopting the portable representation explanation eliminates the need for processes that inherit the temporal structure of its apparent targets. This provides a *prima facie* reason to prefer some versions of content extensionalism over process extensionalism, and an even stronger reason if one respects the content/vehicle distinction and is already committed to a representational theory of perception more generally. Now let us turn to an argument that challenges both branches of extensionalism, by denying successive events are ever perceived together *as present*.

1.4. An Argument Against Extensionalism

Some dispute the supposed ‘brute fact’ of (iii) and argue instead that perceiving something as present implies the events experienced must be simultaneous.⁴⁰ Those critical of extensionalism claim that, for any two events perceived as present, x and y, x must be perceived as happening at the same time as y. So, one can accept (i) and (ii), yet deny that one can perceive non-simultaneous events together as present. Examining a *reductio* argument against (iii) is instructive, even if no one offers such an argument, since the dilemma it poses and the possible ways of responding to it delineate divergent models of temporal experience. The dilemma results from two alternative ways of explaining how one can discern earlier and later events in a perceived succession. The first horn

⁴⁰ Le Poidevin (2007: 81) raises this objection without making the argument explicit when he says, “we could hardly both perceive two events as present *and* perceive one as occurring before the other.” Cf. Kelly (2005b)

employs tensed content or some such modes of presentation, whereas the second reduces an experience of succession to a succession of experiences. One can argue in the following fashion:

- A1) Suppose, for reductio, that successive events are perceived together as present.
- A2) If successive events are perceived together as present, then one can discern earlier and later events within the experience.
- A3) So, one can discern earlier and later events within a present experience.
- A4) If one can discern earlier and later events within a present experience, then either some of the events in the sequence are not perceived *as* present, or the sequence of events are not perceived together within a single experience.
- A5) So, either some of the events in the sequence are not perceived *as* present, or the sequence of events are not perceived together within a single experience.
- A6) If some of the events in the sequence are not perceived *as* present, then it is not the case that successive events are perceived together as present.
- A7) If the sequence of events are not perceived together within a single experience, then it is not the case that successive events are perceived together as present.
- A8) So, contra supposition, it is not the case that successive events are perceived together as present.

On the first horn of the dilemma (A6), earlier events in a rapid sequence are not perceived as present at the same time as later events in the sequence are perceived as present—instead the earlier events may be perceived *as* past when the later events are perceived *as* present. Or, one is merely aware of earlier events *as* past when later events are perceived *as* present. For example, the crackle of a thunder peal is first heard as present, then the crackle is past when the booming rumble is present. Robin Le Poidevin claims that this implication is obvious, and dismisses the idea that non-simultaneous events are experienced as present:

If we have a single experience of two items as being present, then, surely, we experience them as *simultaneous*. Suppose we are aware of A as preceding B, and of B as present. Can we be aware of A as anything other than past? (2007: 87)

According to this reasoning, if I am aware of the crackle as preceding the rumble, and of the rumble as present, then I must be aware of the crackle as past. Thus, contra supposition, successive events are not perceived *together as present*, since each event in a sequence recedes from the phenomenal present into the phenomenal past, where an experience of succession involves apprehending some events as past and the most recent event in a sequence as present.

A further implication of this route is that A and B can be experienced together as present if, and only if, A is simultaneous with B. Targets of experience *as present* are limited to whatever is on the perceiver's relative plane of simultaneity at the moment of experience.⁴¹ Accordingly, successive events, if experienced together, must have modes of presentation distinguishing those present from those just-past, what Edmund Husserl calls "modes of temporal orientation" and the "running-off phenomena" (1893-1917: 27). The basic picture is that for each phase of experience which is, in turn, present, there is a continuous fading into past and further past modes of presentation. "The momentary phases of perception 'sink'; they continuously undergo modification" (1893-1917: 213). Husserl's account is representative of the view implied by the antecedent of (A6), on which a succession of events can be experienced together, but not each event within the sequence as present. Such a view posits that the cognitive system deploys modes of temporal orientation within experience in order to perceive dynamic events, where temporal perception is constitutively dependent on such intentional structure—call these "Intentionalist Models."⁴²

⁴¹ The idea dates back at least as far as Hermann Lotze (1879: 294). For early criticism, see Stern (1897: 330f) who objected to the Lotzean idea, calling it the "the dogma of the momentariness of a whole consciousness or, in other words, of the necessary isochronism of its members".

⁴² Kiverstein (2010) marks the useful distinction between 'intentionalism' and 'extensionalism', and defends what he calls 'weak intentionalism', in contrast to the 'strong intentionalism' of Tye (2003). More recently, Hoerl (2013) also defends this contrast and investigates the differences between these views, to which my discussion is indebted. Dainton (2008) calls these models 'retentionalism', due to Husserl's concept *retention* for the past-oriented awareness, but that choice of terminology limits the models to the tensed variety defended by Husserl and his followers.

On the second horn (A7), a sequence of events is not perceived in a single experience, rather each event in the sequence is experienced successively as present, in turn, not together. In this vein Philippe Chuard claims, “an experience can only represent what happens at a given time” (2011: 8); the scope of direct experience is purely atomistic on his view. So, an experience of succession reduces to a succession of experiences. The experience of the crackle is distinct from the boom and, furthermore, if you discern successive phases of the crackling and successive phases of the rolling boom, then each discernible part of the thunder peal is a distinct percept, not perceived together as present. Experiences as of succession, motion, change, etc., are post hoc representations of some sort produced from sequential static snapshots of property instances at adjacent times. Thus, representing the entire dynamic event of the thunder peal is a cognitive achievement distinct from perception of the successive phases of the thunder. As before, this horn also undermines the supposition, by denying that successive events are ever part of a single experience as present.

The dilemma suggests there are only two ways for discerning early and later events within an experience: either successive events are experienced together under different temporal modes of presentation, but not as present, or successive events are perceived successively as present, but not together. Either way the assumption that non-simultaneous events are experienced together as present is defeated. Does this argument force us to give up on phenomenological claim (iii) and reject Extensionalist Models? Below I argue that there are reasons to resist this conclusion, and defend a plausible reading of (iii).

1.5. Combating the Argument Against Extensionalism

There are at least two ways to respond to the argument. First, the argument relies on the implausible assumption that experiences are a durationless instant. Second, one can object that

(A4) is false because the consequent is a false dilemma. In considering these responses, the second in greater detail (§1.5.2) than the first (§1.5.1), I sketch a representational strategy for explaining how successive events can be experienced together as present.

1.5.1. Experiences are not durationless

A first line of response to the *reductio* argument, points out that it rests on the implausible assumption that the present experience is a durationless instant such that successive events cannot be perceived as occurring together, no matter how brief the interval in which they are contained, which generates the inference to the false dilemma that either some of the successive events within the sufficiently brief interval are not perceived as present or the events are not perceived together within a single experience. The durationlessness assumption implicitly identifies the perceived present with a theoretical objective present. In this vein, St. Augustine argues that an objective present must be durationless, because otherwise some of its temporal parts would be either past or future and thus not present (*Confessions*, Book XI, §15).⁴³

Recall, however, that the claim at issue is phenomenological, not metaphysical; it is, in part, a matter of what seems to be perceived together as present in a single experience. The peal of thunder has discernible earlier and later parts (viz., crack-boom), but I certainly seem to experience the entire brief sound event as presently happening and it is represented in perceptual experience accordingly. If the perceived present were a durationless instant and any interval of time is infinitely divisible into a dense partial-ordering of such instants, then I should be able to represent

⁴³ Dainton (2000: 120) has shown that an argument can be given to argue for a durationless present of experience. Augustine's claim that the objective present is durationless together with presentism (i.e., the metaphysical thesis that only the present is real) jointly entail that if any experience is a real event, then it is durationless. Nevertheless, this argument is wildly implausible on phenomenological and empirical grounds and Dainton rebuts it on those grounds. See also Le Poidevin (2007: 79) for a nice summary of both Augustine's argument and the presentist 'Augustinian' argument that Dainton constructs.

in perception infinitely many distinct phases of the brief thunder peal. On the face of it, this suggestion seems paradoxical or at least nomologically impossible. Barry Dainton suggests as much when he asks, “Physicists currently believe that intervals below the Planck duration of 10^{-43} seconds have no physical significance—is it likely that such intervals have any phenomenological significance?” (2000: 170). The obvious answer to the rhetorical question is: no, it is highly unlikely that we could consciously experience the present on orders of magnitude below those relevant to our best science and undetectable by our best instruments. After all, we develop the mathematical formalisms and instruments of science for the purpose of studying phenomena completely undetectable by our coarse-grained sensory systems.

Furthermore, there are successive phenomena which we are unable to perceive as successive because the stimuli are too rapid. For instance, the way in which the cathode-ray tube works in older computer monitors and televisions exploits our inability to perceive the temporal order of stimuli that occur at too fast a rate. The accelerated beam of an electron gun scans the screen in a fixed pattern at a rate much too fast for our visual system to detect, and results in our seeing the successive patterns of electrons as a simultaneous image.⁴⁴ This sort of phenomenon simply suggests that there are lower-bound thresholds for different sensory modalities which constrain what is consciously perceptible to humans. I discuss lower-bound thresholds in greater detail in Chapter 4.

At this stage it suffices to point out that conscious perceptual experience is importantly constrained by the operational and functional limitations of an organism’s sensory and cognitive systems. We can only hear a certain range of frequencies, we can only see a certain range of light

⁴⁴ Locke [1690/1975, II.XIV.10: 184-85] gives his famous thought experiment of a cannon-ball passing through a room as an example of this sort of phenomenon, but one can reasonably argue that an appropriately situated perceiver could perceive that the successive motions of the cannon-ball were non-simultaneous within the brief interval of the experienced present.

waves with the unaided eye, we can only feel a certain range of temperatures before the tactile sensors give out, and an analogous range of perceptual acuity is true of time perception. So, in addition to providing a perspicuous phenomenology of the contents of experience perceived as present, an account of human temporal experience and time perception should be developed within the actual limitations of our perceptual and cognitive systems. I take this to imply that a suitably naturalized account of time perception should provide plausible interpretations of current empirical research or generate new testable hypotheses for future research. As a start, we should avoid building durationless instants into our models of present experience. Now let us turn to the more constructive reply to the argument against extensionalism

1.5.2. False dilemma: a representational third way available to Content Extensionalism

According to the second response, there is a clear third alternative to explain how one can discern earlier and later events in a perceived succession, consistent with the version of content extensionalism I motivate above: a perceptual experience can simultaneously represent earlier and later events within a brief interval *as* successive, and indicate the dynamic target *as* present. Such an experience involves a representation of the temporal order of the events and an indication that the targets of the experience are all presently happening in immediate succession.⁴⁵

⁴⁵ This suggestion does not imply that we always represent the contents of events in their objective order, only that it is a reasonable explanation of veridical cases of time perception, when the deployment of a temporal representation accurately represents its target. In fact, there are many well-documented illusions like the flash-lag effect (Metzger 1932; Mackay 1958; Nijhawan 1994; Eagleman & Sejnowski 2000) and the cutaneous rabbit illusion (Geldard & Sherrick 1972); studies of both effects provide support for the hypothesis that the temporal content of an event is encoded in neural processing of sensory inputs and then reordered in conscious perception. See Dennett & Kinsbourne (1992), Grush (2005a), and Hoerl (2009) for philosophical discussion of these illusions. On the other hand, the experimental conditions necessary for reproducing these effects exploit the very brief neural latencies of our sensory systems and the effects disappear when the intervals between stimuli are increased. At most, these illusions support the modest claim that temporal processing at the level of neural encoding is not identical to the structure of time perception at the level conscious cognition (which seems obvious!). I will argue later that these illusions provide some support for the hypothesis that duration of the experiential present ranges between 300ms-1s, since the illusory effects exploit processing thresholds at the sub-experiential level.

In this response, I am invoking a useful distinction between indication and representation (Cummins & Poirier 2004, Cummins *et al.* 2008, Cummins & Roth 2010); an indication detects the presence of a target, whereas a representation carries information about the structure of its target. A representation, if veridical, is isomorphic to its target. For example, when a litmus paper turns red, it *indicates* the presence of an acidic solution, but it tells me very little about the structure of that target (e.g. what kind of acid it contains). In contrast, a model of HCl *represents* the molecular geometry of hydrochloric acid, and tells me a great deal about its structure, but it does not tell me whether or not there is any HCl present. Additionally, as I argue above, representation is intransitive and portable. Indication, however, is transitive and source-dependent. To illustrate these properties of indication, let us consider a more developed example.

Take for instance, a Geiger counter, a metal-lined tube with a wire running through its center filled with inert gas, which detects the presence of alpha, beta, or gamma radiation. When the counter audibly “clicks” upon detecting a voltage pulse between the wire and the wall of the tube, it thereby *indicates* that there are alpha, beta, or gamma rays passing through the tube. It does so because radiation ionizes the inert gas contained in the tube creating free electrons, and electricity easily passes through the ionized gas. So, the counter's “click” *indicates* the presence of radiation, where indication is a transitive relation. The example illustrates the transitivity of indication because a “click” indicates a voltage pulse, and a voltage pulse indicates ionization of the gas, which in turn indicates that alpha, beta, or gamma rays passed through the tube, so a “click” on the Geiger counter indicates the presence of radiation. By extension, lots of rapid clicks indicates a strong proximal source of radiation, which is why Geiger counters are useful devices for detecting dangerous levels of radiation. Notice that the Geiger counter does not represent radiation, because it doesn't tell us anything about the structure of the rays being detected (e.g. it cannot tell

us whether the rays are alpha, beta, or gamma), it only tells us that radiation is present. If there is no radiation, then the Geiger counter does not click. So, indication is source dependent in a way that representation is not.

Recall my objections (§1.3.1) to the source-dependency inherent in process extensionalist models due to their commitment to MIRRORING. Such models conflate indication and representation, in particular, by appealing to a causal accounts of representational content, which hold that representation is, or derives from, indicator content. So, process models cannot avail themselves of the response I am developing to combat the argument against extensionalism.

To return to problem at hand, the strategy I am pushing emphasizes that the presence appealed to in claims (ii) and (iii) is phenomenal presence, and thereby denies that indicating events are *present* implies representing them as simultaneous. Phenomenal presence is orthogonal to the exclusive distinction between successiveness and simultaneity. That the successive notes of a Charlie Parker riff are represented together in my experience, and indicated as present, says something both about the temporal order of the dynamic target and the relation I bear to the target, i.e. the target is present over some interval. In this way, temporal perception involves both representational content and indicator content, but the former does not reduce to some concatenation of the latter, since reliable indication is source dependent and representation is not. Merely remembering the same chromatic progression from, say, Parker's "Scrapple from the Apple," represents the same semantic content (if my auditory memory is accurate), but the target is absent, since there are no external auditory stimuli present.

Let us take a spatial analogy to show why this is a coherent way of understanding how successive events can be perceived together as present. When I perceive six dominoes as vertically stacked *there* in front of me, I can discern that certain dominoes are above or below others in the

stack while also being immediately aware that all six are *there*, spatially present, collectively occupying a region of space in my visual field. Does that imply that I am perceiving the six dominoes as exactly co-located? Of course not, that would be absurd, since exact co-location would require that the six dominoes somehow occupy, at the same time, the same region of space with the exact dimensions of a single domino.⁴⁶ My experience represents the stack of six dominoes *as there*, and each domino occupying an exact location above or below others, *as* vertically contiguous. So, just as in the temporal case, spatial presence is orthogonal to the exclusive distinction between co-location and contiguity. Confusing *as stacked there* for *exactly co-located* is an analogous mistake to confusing *as present* for *as simultaneous*.

The first horn of the dilemma (A6) trades on this equivocation, since there are two readings of *as present*, it can be understood either ‘as happening at the same instant’ or ‘as occurring within a brief temporally extended phenomenal perspective’. On the first reading, the original extensionalist supposition [claim (iii)] is obviously false, since events cannot be perceived both as successive and as simultaneous. On the second reading, the conditional (A6) is obviously false, since some events in a sequence not being perceived *as* occurring within the same brief temporally extended phenomenal perspective is not a sufficient condition for denying that successive events are ever perceived as occurring within the same temporally extended phenomenal perspective. The truth of (iii) requires the phenomenal perspective reading and the truth of (A6) requires the simultaneity reading, thus begging the question against extensionalism.

Recall that the first horn of the dilemma is motivated by intentionalist models, which claim that a succession of events can be experienced together, but only one event within the sequence is perceived as present and the other events are experienced as further and further past in relation to

⁴⁶ If that were possible, then it would only appear *as* a single domino, not a stack.

the present event. Since intentionalist models oppose extensionalism on this point and offer a competing explanation of temporal experience, it is imperative to evaluate the model on its own terms.

1.6. Husserl's Intentionalist Model

According to Husserl's Intentionalist Model, if non-simultaneous events are experienced together, then at most one is experienced as present. This is because, for the intentionalist, discerning the temporal order of the successive events in experience derives from the intentional structure of the experience, i.e. the events in the sequence being represented under distinct modes of temporal orientation, only one of which is immanently present. As Christoph Hoerl defines the model, “intentionalism about temporal experience has it that the fact that we can have perceptual experiences, e.g. as of movement or change, is to be explained in terms of the idea of a particular intentional structure that experience possesses” (2012: 381). In order to better understand the intentional structure and how it is supposed to work, below I consider a basic sketch of intentionalism.⁴⁷

Within the intentionalist model, perceptual experience is constituted by, at least, two distinct structural elements that are represented simultaneously: instantaneous present sensory *impressions* together with receding *retentions*, i.e. intentional traces of just-past events. Husserl's later version of the model also posits a third element, *protentions*, i.e. anticipations of the immediate future. Protention is a component of our experience that automatically anticipates the forthcoming phase of an ongoing event, a sort of predictive intention. Each of these three elements are inextricable from the whole experience, as Dan Zahavi describes Husserl's schema of temporal experience,

⁴⁷ Cf. Horwich (1987), Gallagher (1998), Kelly (2005), Strawson (2009), and Kiverstein (2010).

“the basic unit of temporality is not a ‘knife-edge’ present, but a ‘duration-block,’ that is, a temporal field that comprises all three temporal modes of present, past, and future,” (2005: 56). Invoking a unified temporal field makes it sound as though Husserl's model collapses into a version of extensionalism. The significant difference, however, is that instead of positing an extended present, it holds that only the primal impression is present, and experienced as present. Protentions and retentions are future- and past-modified contents of representations, respectively, which determine the temporal horizons—the leading and lagging edges—of our ongoing phenomenal experience. In this way, our experience has tensed contents, or constructs tensed contexts, that make it possible for us to perceive dynamic targets like successions and changes. The continual transformation of contents from protention to primal impression to retention constitutes the temporal structure and phenomenal character from one experience to the next, the temporal structure of perception constitutively depends on the intentional structure of experiencing.⁴⁸ Husserl claims, “since a new now is always entering on the scene, the now changes into a past; and as it does so, the whole running-off continuity of pasts belonging to the preceding point moves 'downwards' uniformly into the depths of the past” (1893-1917: 28). Figure 3, below, provides a reconstruction of the basic features of the Intentionalist Model, illustrating Husserl's "running-off continuity" hypothesis:

⁴⁸ “The concrete and full structure of all lived experience is consequently *protention—primal presentation—retention*. Although specific experiential contents of this structure change progressively moment to moment, at any one given moment this threefold structure is present (synchronically) as a unified whole.” (Zahavi 2005: 57).

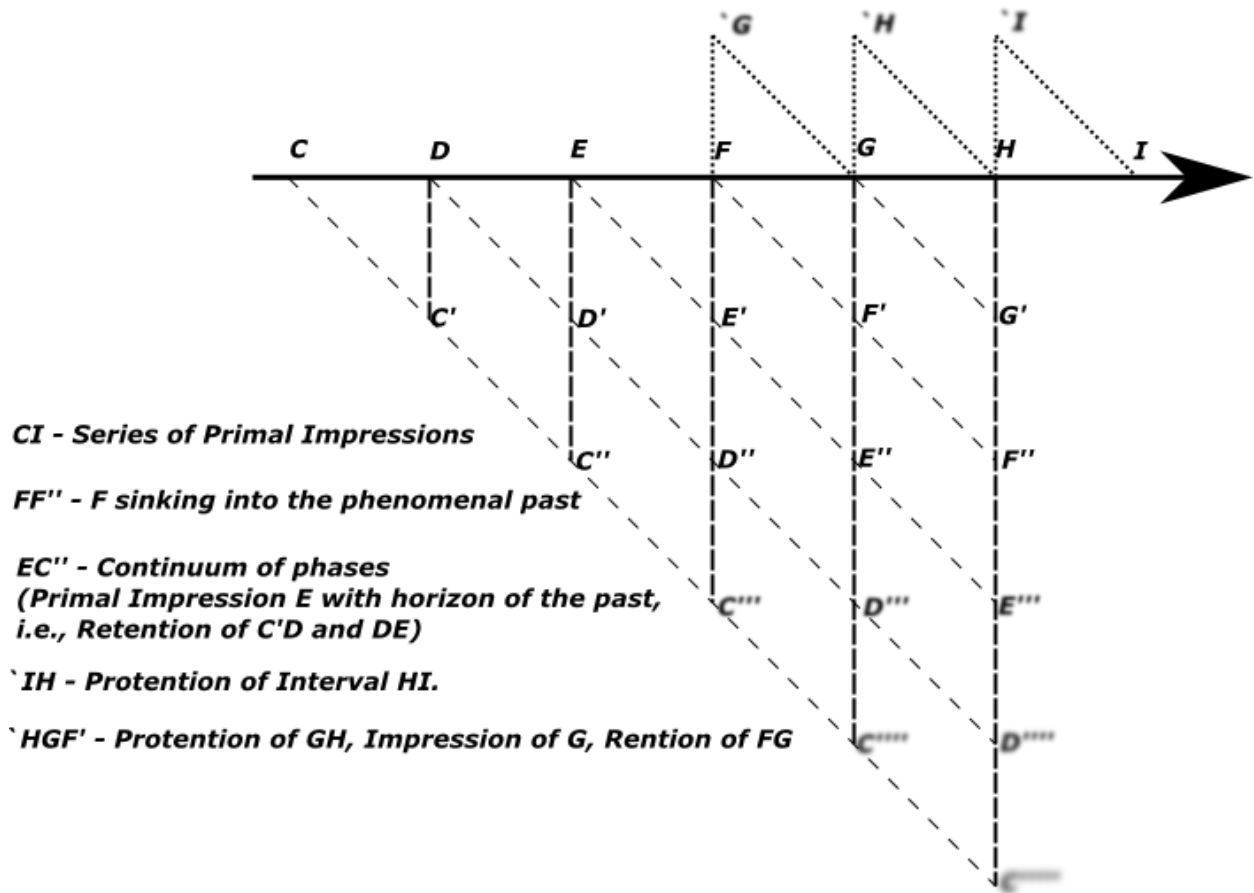


Figure 3: Husserl's Intentionalist Model⁴⁹

In the figure, the central horizontal line CI represents a series of primal impressions in experience, perhaps hearing a child recite the alphabet. The descending vertical lines, like FC'', represent a continuum of retention phases that accompany each successive primal impression. Primal impression E is retained at F as E' and apprehended along with the retentions, i.e. further past mode representations of the previous primal impressions D and C, which are denoted by D'' and C''', respectively. Likewise, F' is the retention of F accompanying the primal impression G. The diagonal dashed lines represent the ongoing retentional modification of primal impressions fading

⁴⁹ I generated this figure by extrapolating from Husserl's own diagram (1893-1917: 28) and Dainton's reconstruction (2000: 152). Compare to Merleau-Ponty (2004: 484) and Gallagher's modified version (1998: 50).

into the past, where the closer a retention is to the horizontal line, the more recent it is in the stream of conscious experience. So, at E, the impression of D is just-past, as D'. At F, the prior impression D is experienced as further past than E, hence D'' is lower than E' on the descending vertical; also at G, D is experienced as more past than it was at F, so D''' is further from the horizontal than D''.

According to the intentionalist model, perceptual experience is inexorably and continuously being updated, as Husserl claims, “a pushing back into the past continually occurs. The same continuous complex incessantly undergoes a modification until it disappears; for a weakening, which finally ends in imperceptibility, goes hand in hand with the modification” (1893-1917: 30-1). To illustrate the so-called ‘weakening’ in the figure, at H, the retention of D has faded almost entirely beyond the horizon of recent ongoing experience, to its eventual imperceptibility which I have represented by blurring the retention D'''. I think this helps to appreciate Husserl’s conception of the indefinite and continuously changing boundaries of the temporal field (*Zeitsfeld*) of experience, which bears striking similarities to the fields posited by Content Extensionalism with the important difference that tensed modes delimit the field for the Husserlian intentionalist model.

One should also bear in mind that the figure abstracts away from the analog continuity of actual experience, by positing discrete primal impressions, thereby digitizing the intentional complex of protention-impression-retention. For Husserl, temporal experience is continuous, such that between F and G there is a dense continuous series of other primal impressions not represented in the diagram, since doing so would clutter the figure and make the model more difficult to explicate. Also, the vertical dashed lines, like EC'', consists in a continuum of retention phases, where each continuum of retentions represents immediately receding impressions and prior retentions undergoing retentional modification.

Figure 3 also depicts the anticipations of future primal impressions, i.e. protentions, the functional directedness of perceptual experience towards what is coming, with the vertical dotted lines `GF, `HG, and `IH, which represent the protentions of intervals FG, GH, and HI, respectively. In contrast to the detailed analysis of retention, Husserl actually says relatively little about protention, which has led others to largely ignore it as well.⁵⁰ Protention cannot simply be given a symmetrical analysis to retention for two distinct reasons. First, as just mentioned, ongoing temporal experience always consists in a retentional continuum of contents fading into the past of experience, eventually disappearing beyond the horizon of experience, viz. the running-off continuity hypothesis. Protention is a projective function of experience, the expectation that experience will continue in some way or other. Yet, it makes no sense to posit a protentional continuum since the horizon of future percepts does not reach very far, and is somewhat indeterminate (hence my blurring of `G, `H, `I). Sean Gallagher makes precisely this point, “protentioning cannot be a gradual and orderly fading into obscurity; it must be an unregulated, relatively indeterminate, and temporally ambiguous sense of what is to come” (1998: 68). Protention is more of an open anticipation of the unbidden and inevitable continuation of experience. Of course, we can and do anticipate specific future continuations of larger-scale events. I expect the child to continue reciting the alphabet, in order, until she reaches ‘Z,’ but that sort of determinate prediction is not confused with perceptual experience and thus is not a function of protention. Whereas, there is a sense in which I perceive or pretend `G before the child voices “G,” I anticipate what I am immediately about to hear. Listening to familiar music has this effect, as well.

⁵⁰ E.g., Barry Dainton sets it aside by saying, “Husserl is right to point out that we are not surprised that our experience continues; at any moment we expect that *something* will come next, experientially. But since Husserl does not give great emphasis to the protentional aspect of experience, nor shall I.” (2000: 153)

Second, the content of retentions are fixed by the impressions from which they descend. That which is intended by the retentional modification is determined, what the modification changes is the temporal orientation and tensed context from one moment to the next. Protention is entirely different in this respect, “protentioning is necessarily, as it functions, an unfulfilled intentioning directed toward an immediate but indeterminate about-to-become” (Gallagher 1998: 68). So, protention is unlike retention, in that it cannot consist in a continuum and its content is indeterminate.

One might think that protention is a gloss on the “forward-looking” trajectory estimation function that I ascribe my preferred version of content extensionalism, but I think the differences actually favor extensionalism over intentionalism. Recall that a trajectory estimation function algorithmically predicts future transformations of represented events by filtering the noise from observed signals and exploiting a prediction-correction cycle to generate statistically optimal state estimations (Grush 2005a, Kalman 1960). Such state estimations have determinate content, rather than the indeterminacy built into the future-tensed mode of Husserlian protention. In this way, such a model provides a detailed and computationally sound manner for how a system of temporal perception constructs the leading edge of a temporal field of content, based on the most probable future state estimation. In comparison to this systematic and computable function, Husserl and his apologists, like Gallagher and Zahavi, give vague accounts of protention, as a function for intending indeterminate future contents, describing it as, ‘unregulated, relatively indeterminate, and temporally ambiguous sense of what is to come.’ On this score, a version of content extensionalism that posits a trajectory estimation function provides a detailed account to better explain how temporal perception can reliably represent near future contents in present experience,

whereas intentionalism waves its hands at a functionally ambiguous component of the intentional structure of our experiences.

One might think that intentionalism can easily adopt the trajectory-estimate hypothesis to improve the account, but there is reason why doing so would depart significantly from the intentionalist analysis. Trajectory estimates are probabilistic predictions based on noise filtering, for which tense plays no functional role. Protentions, by contrast, are future tensed anticipations of immanent primal impressions, where the tense of the content plays an explanatory role in the relation that obtains between protention, primal impression, and retention in the intentionalist framework. As a primal impression, say *D*, is experienced and sinks into the past as *D'*, *D''*, *D'''*, etc., all that retentive modification changes is the tensed mode of presentation while *retaining* the content *D*; I anticipate that I will hear a *D* after *B* and *C*, and then *D* fades further and further into the past. On the trajectory estimate hypothesis, however, the entire trajectory is re-estimated through prediction-correction feedback cycles, entailing that some earlier perceptual information can be adjusted or overwritten to generate better estimates of the entire trajectory. Rick Grush emphasizes this significant difference between the trajectory estimation model and Husserl's analysis:

Husserl sees the relation between protention, retention and primal impression as one of 'modifying' items that remain in other respects constant. This is suggested by the name 'retention' itself, but is also explicitly stated as a feature of the analysis. On the trajectory estimation model this is not what happens. As time progresses, the *entire trajectory* is re-estimated, with the consequence that some parts of the estimate can be changed. For example, according to the trajectory estimation model, in the cutaneous rabbit situation, at the time of the second tap the relevant part of the trajectory estimate is 'second tap at the wrist'. If Husserl were correct about the way that retention operates, then this estimate should simply sink back, unchanged but for its temporal marker, as time progresses. But as we have seen, this need not happen. At some point, if the sequence of stimuli is right,

the trajectory estimate will be modified so that the relevant retention will have the content ‘there was a second tap *proximal to the wrist*’. And this will be the correct explication of the content of that retention, at that time, even though there never was a primal impression with that content. On Husserl’s analysis, temporal illusions should not be possible. But they are possible, so Husserl’s analysis can’t be right in this respect. (2006: 449)

Although Husserl makes an important insight by including protention in his model of the intentional structure of time consciousness, the model is ill-equipped to explain the mechanism of trajectory estimation without abandoning both the tensed mode of presentation explanation and his conception of ongoing retentional modification. Content extensionalism, however, can make good on the promise of explaining how an ongoing predictive mechanism plays a functional role in representing dynamic targets in experience.

To further complicate the intentionalist model, slightly, one might experience multiple sensations together simultaneously, e.g. seeing lightning begin to flash and hearing a dog begin to howl. If those stimuli are initially experienced together, the entire constellation of simultaneous experiences undergo modification together as they sink further into the past. As Husserl claims, “several, many primal sensations occur 'at once'. And when any of them elapses, the multitude elapses ‘conjointly’ and in absolutely the same mode with absolutely the same gradations and in absolutely the same tempo” (1893-1917: 77). If stimuli are perceived simultaneously, then they degrade and fade together in synchrony and at the same pace. There is a general exception to this conjoint elapsing; namely, when various simultaneous sensations are parts of distinct events of varying lengths, “series of primal sensations constitutive of the enduring immanent objects are variously prolonged, corresponding to the varying durations of the immanent objects” (1893-1917: 77). In a simpler paraphrase, sensations that constitute initial phases in a longer event may continue to fade in connection to that event, when the initial phase in a briefer event has already faded into

obscurity. For example, the series of sensations constituting the visual lightning strike experience will fade beyond the retentional horizon of experience, whereas the initial phases of the dog howl experience continue to “flow away,” relative to the prolongation of the howl.

Does this seem like a perspicuous account of temporal experience? When seeing lightning strike and hearing a dog howl at roughly the same time, do the early phases of those events seem to fade in synchrony? Another difficulty with intentionalism is not in the abstract conception of Husserl’s model, but rather its failure to adequately describe our actual experience or the contents of those experiences. It does not seem that I am presently experiencing fading traces of retentional continua, call this the ‘Lingering Contents’ objection (Dainton 2000).

I do not perceive fading lightning flashes and previous phases of howling, I hear the present howl as present. To further illustrate, when I witness the execution of a 6-4-3 double-play in a baseball game, I first perceive the toss from short to second, then the throw from second to first (along with a retention of the toss from short to second).⁵¹ Husserlian intentionalism, on the other hand, gives a much more complex account: if the primal impression is momentary, then I should be conscious of the retentional fading of each successive momentary phases of the ball’s trajectory, as well as the countless fading continua of each of the player’s movements. But, there are no “comet-tails” of experiential contents. For instance, if you are listening to music on your stereo and someone suddenly disconnects the speakers from the receiver the music halts, the most recent melodic phrases do not linger on in experience, as we should predict if intentionalism were correct. So, Lingering Contents shows that intentionalism is misleading, at best, and a false account of present experience, at worst.

⁵¹ This might work if the two distinct throws were within two adjacent experiences *as* present and an intentional analysis is merely employed to account for the continuous succession of the double-play as a whole, a longer temporal gestalt. In such a case, however, the resulting theory would be a version of Content Extensionalism with an ancillary intentional analysis to account for temporal phenomena extending beyond the present.

A related problem for intentionalism is what is sometimes called this the ‘Clogging of Experience’ objection (Dainton 2000). According to the intentionalist model, at any given moment, I must be apprehending an infinite amount of content due to the retentional continua of every successive phase of experience. If so, then observing a simple double-play would be a dizzying experience, listening to music would be overwhelming with all the layers of auditory continua, in general experience would be clogged by surplus content. But, it is impossible to perceive an infinite amount of content and, even if it were possible, it would make temporal perception much too computationally expensive—needing to devote all of the brain's cognitive resources to the task, thereby making it near impossible to engage in the world. This is not a very promising model for reproductive fitness. If our system for temporal perception were this taxing, then our species would have been evolutionary rejects long ago.

Both Zahavi (2005, 2007) and Gallagher (2003) defend the model against these related objections by appealing to the strictly intentional character of both protention and retention. That is, retentions do not supply additional content, they only modify our presently apprehended contents and what is retained is simply the meaning or significance of the just-past contents. Zahavi claims:

...the protention and retention are dependent moments of any occurrent experience. They do not provide us with additional intentional objects, but with a consciousness of the temporal horizon of the present object. (2005: 58)

This reply seems to supply answers to the Lingering Contents and Clogging of Experience objections to intentionalism by emphasizing the intentional structure of experience, and rejecting a commitment to persisting contents. If all that is being modified in retention is the tensed horizon of our past experiences in relation to the present primal impression, then retentions functions like a tense-marking working memory and just-past contents would not linger on in present experience.

Likewise, if retention only modifies the tense of just-past contents in relation to the present experience without generating additional intentional objects, then retentional continua do not clog our experience in the way the objection suggests. In this manner, the Zahavi-Gallagher line of response provides reasonable rejoinders to the standard objections by clarifying how the intentional structure retains past contents.

But, at what cost? In making this clarification, it is difficult to grasp how intentionalism is able to explain how we perceive dynamic targets as present. If the only genuine content is the now-phase of an event that is consciously apprehended in a primary impression, then we can never apprehend motion, change, or succession. We can only appeal to the retained meanings of just-past contents to discern that something *has* moved, *has* changed, or something *has* succeeded something else. On the Gallagher-Zahavi purely intentional interpretation, at most, we perceive the phenomenal content of the primal impression (not the primal impression itself, rather the now-phase of an event segment that is apprehended in the primal impression), and both protention and retention are only intentional horizons and modifications of the successive apprehensions. So, intentionalism, on the revised reading, seems to make representation of ongoing events a matter of intentional recognition of contents and tensed relations that obtain between them, rather than perception dynamic targets.

Certainly we can countenance intentional features of temporal experience, features that inform our phenomenal contents, including tensed modes of temporal orientation, but a purely intentional account fails to do justice to the perceptual component of our actual experience. This should be taken as a significant cost, since we initially set out to disclose the conditions for the possibility of temporal experiences targeting dynamic events like birds flying, thunder rolling, or a saxophone melody meandering. A proponent of the model may modify the intentional reading to preserve the

contents apprehended in the primal impression, but this would only give us a continuous series of sensory impressions, and intentionalism would collapse into the view according to which the representation of an ongoing dynamic event, like a bird in flight, reduces to discrete perceptions of each temporal part of the event.⁵² The revised version of intentionalism avoids the lingering content and clogging of experience objections, but at the expense of either disconnecting our temporal experience from perceptual contents or only positing a continuous series of momentary impressions. Therefore, intentionalism is insufficient by itself for adequately accounting for phenomenological claims (i-iii), and *a fortiori* is insufficient to provide an explanatory analysis thereof.

Unlike intentionalist models, the representational strategy, available to content extensionalism, forgoes tensed modes of temporal orientation, and instead posits a mechanism by which a cognitive system intends dynamic targets of sufficiently brief interval, where the semantic content of the token mental representation represents the temporal structure of the extended events (e.g., the crack of the thunder peal preceding its boom) and the experience also indicates one's context-sensitive relation to the target event, i.e. the brief thunder peal in its entirety *as present*. In terms of cognitive economy, the representational strategy enables a perceptual system to group together connected sequences of events within a sufficiently small interval, which is plausibly a more efficient solution to the cognitive task than representing each instantaneous phase of an event individually. Contrast this to the view implied by the second horn of the dilemma (A7), which claims that sequences of non-simultaneous events are never perceived together within a single experience. From which it follows, representations as of succession reduce to successive perceptions of finely individuated atomic events—call these “Atomistic Models.”

⁵² On such a reading, intentionalism collapses into a version of temporal atomism, the model I introduce briefly below and argue against at length in Chapter 2.

An atomistic model holds that a present perceptual experience can only represent what happens at that time and is not divisible into earlier and later parts in perception. This move simply denies the phenomenological claim (ii), that we do perceive dynamic events as present, such as successions, movements, and changes. Such a denial implies that any purported dynamic experiences are not perceptual at all, but are inferential and combinatorial through and through. For instance, some models posit the recruitment of some form of memory in order to make ongoing inferential judgments of succession on the basis of successive discrete perceptions. Denying that we ever experience dynamic succession amounts to a denial of this widely endorsed phenomenological difference, between experience of succession and a succession of experiences.⁵³ Recognizing this distinction is part of the motivation for the early and continued philosophical discussion of temporal experience. Consider each of the following passages:

The representation of something persisting in existence is not the same as a persisting representation. (Kant 1781/87: Bxli)

A succession of feelings, in and of itself, is not a feeling of succession. (James 1890: 629)

Obviously we must distinguish...the perception of a sequence from a mere sequence of perceptions. (Sellars 1968: 232)

It has long been recognized that a succession of experiences is one thing, and an experience of succession is quite another. (Dainton, 2008: 623)

The fact that the stimulus endures still does not mean that the sensation is sensed as enduring; it means only that the sensation also endures. The duration of sensation and sensation of duration are two very different things. And this is equally true of succession.

⁵³ See Herbart (1834: 133), (James 1890: 629), (Strong 1896: 153), Broad (1923: 351), (Paton 1929: 318), Gallagher (1998: 22), Dainton (2003: 2), Lockwood (2005: 363); for a dissenting opinion, see Kelly (2005).

The succession of sensations and the sensation of succession are not the same. (Husserl 1893-1917: 12)⁵⁴

To illustrate the distinction, a single experience of a thunder peal as present is markedly different than successive experiences of perceiving the lighting flash as present, then the intervening silence as present, and then the thunder peal as present. In the former experience, on one hand, I seem to perceive the crack and boom of the thunder peal together as present while also being aware that the crack occurs before the boom. On the other hand, I do not seem to perceive the lightning, silence, and thunder together as present; rather, the perceptions succeed one another, each of which is individually experienced as present within a sufficiently brief interval.

According to the atomistic model, in neither case do I perceive a brief dynamic event as present, instead the purported experiences are comprised of successive simultaneous snapshots of the ongoing events. Judgments of dynamic qualities are made after the fact, thus not experienced together as present. This shifts the burden of explanation onto the atomist, to explain why there seems to be difference in these cases and why we seem to have such perceptual experiences of dynamic events when their model entails that we do not. Such an error theory, would have the additional burden of providing a principled distinction between experiences of illusory dynamic targets, like musical hallucinations, and veridical experiences of sound events. The representational explanation available to Content Extensionalism does justice to the phenomenological difference and provides a framework for understanding temporal illusions and hallucinations, faring better than the Atomistic Model on both counts.⁵⁵

⁵⁴ For similar observations, see Broad (1923: 351), Gallagher (1998: 22), Dainton (2003: 2), Lockwood (2005: 363); for a dissenting opinion, see Kelly (2005b).

⁵⁵ I address atomistic models in more detail and some of their error theory proposals (viz. Chuard 2011, Paul 2011) in Chapter 2. In Chapter 4, I argue that Content Extensionalism also fares better than Atomism with respect to explaining *how* the mechanisms for temporal perception are physically realized in neural architecture.

1.7. Conclusion

In responding to the Argument Against Extensionalism, I have sought to provide a workable solution for defending Content Extensionalism, and accommodate three phenomenological claims that I motivated at the outset: (i) temporal perception targets dynamic events which instantiate temporal properties and stand in temporal relations, (ii) that humans perceive dynamic events as present, and (iii) that successive events of brief duration are experienced together as present. I have not shown that Content Extensionalism is the only model in town. I have given a detailed analysis of both forms of extensionalism. I argued that process extensionalist models are committed to a property inheritance hypothesis, MIRRORING, which generates problems of source-dependency, where one possible way out involves endorsing some form of anti-representationalism about perception. Additionally, I have argued that content extensionalism has explanatory advantages when paired with a theory of mental representation that distinguishes representation from indication, and thereby recognizes that representations are source-independent isomorphs of their intended targets, which provides a straightforward account of claims (i-iii). I also examined Husserlian intentionalist models, and argued that it fails as a model of present experience that accommodates all three claims. Where intentionalism actually shares some insights with content extensionalism, regarding the function of intending future contents, I argue that a content extensionalist model that posits a trajectory estimation function is better-suited to explain how this mechanism works, making the Husserlian analysis otiose. This chapter introduces my model-based approach to temporal perception, provides some initial defense of content extensionalism, and advances some objections against the contending competitors.

2. MODELING CONSTANT MOTION PERCEPTION

2.1. Introduction

We seem to see raptors gliding in flight, leaves falling, bicycles cruising past, second-hands sweeping across the face of an analog clock, among countless other examples of constant motions perceived by humans. Seeing objects in motion is an ordinary everyday feature of visual experience, so ordinary that some take our visual capacity to target and track objects in constant motion to be an obvious fact (Phillips 2011: 808). In this context, what is meant by ‘seeing constant motion’ is that ‘there is no period during one’s visual experience of the moving target over which it does not appear to be changing position.’ In this sense, seeing constant motion is simply seeing something moving between stops, even if you never see the object at rest (e.g. a bee flies into your visual field, buzzes around, and flies out of sight). Observing a cardinal fly from a branch in one tree to another, the bird’s flights between the branches count as instances of constant motion, since the cardinal does not appear to pause or stop in mid-flight. Watching a pitcher throw a baseball, where the ball travels along a parabolic path after being released from the pitcher’s hand counts as constant motion. Windmills spinning, snakes slithering, hockey pucks sliding, and vehicles speeding are all constant motions observable by humans.

The plethora of examples helps illustrate that, on this broad understanding of constant motion, it neither implies constant velocity nor constant direction. Pitches decelerate, speeding vehicles accelerate, slithering snakes take a meandering path, birds and bees change direction in flight, but insofar as the objects do not appear to stop during the periods over which they move, they satisfy the criterion for observable constant motions. Given their prevalence, putative experiences of seeing constant motion are some of the primary visual phenomena for which a model of temporal perception ought to have an account.

I say ‘putative experiences’ to avoid begging questions, because not everyone accepts that we perceive motion, even if we obviously seem to, since seeing motion would require perceiving the temporal relations between non-simultaneous events. For this reason, temporal atomism (hereafter ‘atomism’), the view that perception can only represent what happens at a given time, denies that we perceive constant motion, but develops an explanation of how a series of successive static experiences produces the phenomenal seeming of motion perception (Le Poidevin 2007, Chuard 2011, Paul 2010). The atomist model of perception holds that representations of motion over time reduce to a series of static percepts at a time, experienced sequentially. In brief, temporal atomism is the thesis that creatures like us are only capable of perceiving what is happening at a given time. If so, then we do not perceive temporally extended events instantiating temporal properties and relations.

By contrast, content extensionalism holds that we do perceive temporal relations between non-simultaneous events, and we perceive motion in virtue of representing temporally extended, albeit brief, phases of ongoing events. For content extensionalism, perceptual representations of constant motion are not reducible to mere successions of static atomic perceptions representing what happens at a given time. Rather, according to the content extensionalism I defend, seeing an object in constant motion requires sampling visual information about object’s trajectory over multiple temporal scales and continuously integrating the information, from which perceptual representations of extended phases of the object’s motion are extrapolated.⁵⁶ Suppose, for example, seeing a baseball in motion is a result of sampling the ball’s trajectory at both 20-50ms and 150-300ms, integrating distinct information from the samples (e.g. angular rotation cues at 20-50ms and velocity cues at 150-300 ms), and extrapolating a representation of the ball’s motion including

⁵⁶ In Chapter 4, “Multi-scale Sampling and Integration as a Basis for Temporal Perception,” I argue for the multi-scale sampling hypothesis at-length and make the case that it is a proprietary hypothesis of content extensionalism.

predicted future locations—continuously updated by a correction-feedback loop.⁵⁷ On this way of modeling temporal perception, experiences of constant motion are not reducible to a series of static atomic perceptions, because perceptual representations are generated and updated by information gleaned from the motion-stimuli across multiple temporal grains.

From these brief glosses and the contrast of the two models, there appears to be a substantial disagreement between atomism and extensionalism, which the case of motion perception illustrates. Atomism contends that we only perceive what happens at a given time and that putative experiences of motion reduce to a series of successive static perceptual “snapshots,” whereas content extensionalism denies the reduction to a static series and instead holds that perceptual representations of constant motion derive from integration of information sampled over multiple temporal scales.

In what follows, I articulate and explore the nature of the disagreement between these two primary contenders in the temporal perception debate, and defend content extensionalism.⁵⁸ In §2.2, I highlight some of the primary motivations for endorsing atomism, in order to get a better picture of the differing background commitments and intuitions. Since atomists often appeal to British empiricism for the historical provenance of their view, in §2.2.1, I briefly evaluate the Lockean motivations for atomism. Another central feature of atomism is a mereological conception of experiences, such that purported experiences of extended temporal contents, like

⁵⁷ See Chapter 4, “Multi-scale Sampling and Integration as a Basis for Temporal Perception”

⁵⁸ In Chapter 1, “Modeling Present Experience,” I discuss other versions of extensionalism and Husserlian intentionalism. In the present chapter, I focus on atomism and, my preferred model, content extensionalism. Two reasons for this restriction, one programmatic and one philosophical. First, the first chapter serves partially as a survey of possible models and where content extensionalism fits in relation to the other models, but I also offer arguments against process extensionalism and intentionalism in that chapter and I take atomism to be the strongest opposing view. Second, intentionalism can be interpreted in at least two different ways (departing from Husserl orthodoxy), one by which it approximates content extensionalism and the other by which it approximates atomism; since either view can adopt some insights from intentionalism, including it here would needlessly complicate the analysis in the present chapter.

seeing constant motion, are composed by successively combining atomic temporal parts (i.e. perceptions at a time), and the purported extended “whole” experiences supervene on and are reducible to the successive atomic perceptions of which they are composed. In §2.2.2, I weigh in on Philippe Chuard’s (2011) Mereological Argument for the ontological priority of atomic perceptions and respond to the challenge it presents to some versions of extensionalism.

In §2.3, I develop arguments in defense of content extensionalism, challenge atomism, and appraise the possible rebuttal strategies available to atomism. The apparent phenomenology of extended temporal experiences, like seeing constant motion or hearing melodic progressions, provide strong *prima facie* reasons to endorse some form of extensionalism or, at least, find counter-intuitive the atomist’s denial that we ever perceive temporal relations between non-simultaneous events. In §2.3.1, I argue that the apparent phenomenology places a burden of explanation on atomism, requiring an error theory to explain away our putative perceptions *as of* constant motion and make their anti-realism about extended experiences palatable. In §2.3.2, I further strengthen the *prima facie* case in favor of extensionalism by arguing that a wide-range of cutting-edge neurocognitive and biological research programs operate on the presupposition that humans and non-human animals perceive constant motion. I proceed to examine the hypothesis that visual motion processing is realized in the middle temporal area of the visual cortex and the pathology that results from damage to that area, known as *cerebral akinetopsia*, wherein the patient exhibits deficits in global motion perception (Zeki 1991, 2015). I discuss the well-known case study of akinetopsia patient LM (Zihl et al. 1983, Baker et al. 1991), and argue that in order to explain LM’s neuropathology atomism must resort to positing dubious auxiliary hypotheses, which mark significant departures from prevailing neuroscience.

After establishing the *prima facie* case in favor of content extensionalism, in §2.3.3, I charge atomism with an error theory, charitably reconstruct their standard zoetropic strategy for explaining away the apparent phenomenology, and criticize the zoetropic strategy. In §2.3.4, I reconstruct a standard version of the Individuation Argument for extensionalism and explain its weaknesses as strategy for defending extensionalism.

In §2.4, I utilize a version of Zeno's familiar puzzle of motion, survey some common mistaken solutions, and explain the now standard Russell-Salmon 'At-At' motion solution to the puzzle. I draw analogies between Zeno's puzzle and the temporal perception debate, and argue that the atomist explanation of motion experience is analogous to Zeno's failed solution to the original puzzle and that content extensionalism provides a preferred explanation consonant with the Russell-Salmon solution. I conclude by taking stock of the debate between atomism and content extensionalism.

2.2. Motivations for Atomism

2.2.1. Lockean Motivations

Atomists often attribute the historical provenance of their view within empiricism and Locke's conception of an instant. On one interpretation, Locke suggests that we individuate moments of experience by the ideas we can entertain at any one time. If we perceive no succession (even if there is one), then this constitutes an experiential instant. Consistent with the claims of atomism, a mental instant has some duration (not durationless), although it seems instantaneous to us. Locke illustrates the hypothesis by appealing to the example of a cannon ball passing through two walls of a room and taking with it the flesh of a man:

Real succession in swift motions without sense of succession. The reason I have for this odd conjecture is, from observing that, in the impressions made upon any of our senses, we

can but to a certain degree perceive any succession; which, if exceedingly quick, the sense of succession is lost, even in cases where it is evident that there is a real succession. Let a cannon-bullet pass through a room, and in its way take with it any limb, or fleshy parts of a man, it is as clear as any demonstration can be, that it must strike successively the two sides of the room: it is also evident that it must touch one part of the flesh first, and another after, and so in succession: and yet, I believe, nobody who ever felt the pain of such a shot, or heard the blow against the two distant walls, could perceive any succession either in the pain or sound of so swift a stroke. Such a part of duration as this, wherein we perceive no succession, is that which we call an instant, and is that which takes up the time of only one idea in our minds, without the succession of another; wherein, therefore, we perceive no succession at all. (*Essay*, II.xiv.10)

Atomists interpret this passage as Locke defining an ‘instant’ as ‘the time of only one idea’ and thereby expressing an atomistic “snapshot” view of temporal experience. Locke observes that there is ‘real succession in swift motions without sense of succession,’ and claims that there are motions that our human senses are too coarse-grained and can only perceive succession to a ‘certain degree.’ With respect to this inability to perceive fast motion, Locke hypothesizes that we cannot perceive rapid successions below a certain threshold even in cases where it is otherwise apparent that a succession took place. Atomists thereby take Locke as a forerunner of their view by acknowledging the limitations of our perception in perceiving fast motion and asserting that an experiential instant is only extended enough to entertain ‘one idea.’

It is not altogether obvious, however, that Locke’s definition of instant implies the atomist thesis that one can only perceive what occurs at a given time. Locke defines ‘an instant’ as, ‘that which takes up the time of only one idea in our minds,’ but that does not obviously place restrictions on the complexity of the idea that can be entertained in such an instant. After all, Locke describes the mental operation of “Composition” to be the function which, “puts together several

of those simple ones it has received from sensation and reflection, and combines them into complex ones” (II.xi.6). I can perceive a butterfly because my mind combines the various simple ideas delivered via the senses (e.g. shapes, colors) along with general abstractions (e.g. antennae, wings, proboscis) to arrive at complex idea of a butterfly. Locke holds that if I entertain multiple ideas simultaneously, then my complex mental state constitutes non-inferential knowledge of the agreements between those ideas (Weinberg 2016). Although I must entertain the ideas simultaneously, it does not entail that the source of those sensations must occur simultaneously, i.e. in an instant. I could, for example, observe the butterfly land on a flower and begin probing with its proboscis, and thus perceive the complex idea of pollination by simultaneously holding in my mind the brief succession of movements carried out by the butterfly. So, arguably, although an instant is the time of only one idea in our minds, that idea can be complex and represent an extended event.

Atomists are likely to respond to the previous argument by appealing to Locke’s discussion of the mental faculty “Retention,” which includes both contemplation and memory (II.x). The atomist can claim that the complex idea of the butterfly’s pollinating actions is only possible due to retaining the succession of sensory ideas of the butterfly over several instants that together compose the complex idea of the extended pollinating event, “by keeping the idea which is brought into it, for some time actually in view, which is called contemplation” (II.x.1). According to this line of response, I can know the butterfly is pollinating in virtue of my present sensations in combination with the retained ideas of the previous states of the butterfly. On this interpretation, one can see more clearly why atomists often identify Locke as an early representative of their view. Locke’s concept of an instant, the combinatorial operation of composition, and the role played by the faculty of retention all resonate with the central features of atomism, since atomism claims that

we only perceive what happens at a given time and that putative experiences of extended events, like motion, result from successive combinations of static “snapshots.” We should also flag that the function of composition in Locke’s theory of ideas, i.e. combining simple ideas into complex ones, lends itself to atomism’s mereological conception of experience, such that temporally extended experiences are composed of their temporal parts arranged successively. I now turn to the argument based on the mereology inherent in the atomist model.

2.2.2. Mereological Argument

Philippe Chuard’s (2011: 11-16) Mereological Argument presents a compelling challenge to extensionalist models, by making the case that whole temporal experiences (e.g. seeing a butterfly light upon a zinnia bloom to feed) are nothing over and above their parts experienced sequentially (e.g. seeing the butterfly 3cm away from the zinnia @ t1, the butterfly 2cm from the zinnia @ t2, the butterfly 1cm from the zinnia @ t3, the butterfly probing the zinnia with its proboscis @ t4). If an experience as of succession is explained entirely in terms of perceiving a series of successive events, then there is no reason to posit extended temporal experiences. Chuard’s move puts pressure on extensionalist models from two directions: a) undermining the common extensionalist intuition that an experience of succession is not reducible to a succession of experiences, and b) shifting the burden of proof onto the extensionalist to identify a property (or set thereof) which is not grounded in a succession of its temporal parts.

Chuard begins the argument by establishing what he takes to be a very minor point, viz. that there are very brief or instantaneous perceptual experiences. By extension, brief near-instantaneous experiences are the temporal parts of the purported temporally extended experiences posited by extensionalism. He explains how this lemma is easily derived from common criteria for

individuating experiences. For example, it is fairly uncontroversial that differences in representational content provide a basis for individuation, which he labels the ‘content principle’: “If experience e_1 ’s representational content $\neq e_2$ ’s representational content, then $e_1 \neq e_2$.” (2011: 12).

Clearly, this principle can be employed to distinguish between types of experiences. Different sensory modalities produce experiences with distinct representational content. For instance, smelling an odor is different type of experience from hearing a sound, so olfactory experiences are distinct from auditory experiences. Also, the content principle differentiates types of experience within a sensory modality. Hearing a C# has different representational content from hearing a G, so tokens of those types of experiences are distinct experiences.

Chuard argues that the content principle entails that the temporal parts of temporally extended experiences are distinct experiences. The butterfly pollinating the zinnia example illustrates his point. The temporal part of experience E @ t_1 represents the butterfly 3cm away from the zinnia, the temporal part of E @ t_2 represents the butterfly 2cm from the zinnia, the temporal part of E @ t_3 represents the butterfly 1cm from the zinnia, the temporal part of E @ t_3 represents the butterfly probing the zinnia with its proboscis, etc. Since each temporal part of the experience represent distinct spatial relations between the butterfly and the zinnia, the temporal parts have different contents. So, by the content principle, each of the temporal parts of E are distinct token experiences of different types.

The content principle argument purports to show that temporally extended experiences have temporal parts that are themselves experiences. Chuard takes this to be uncontroversial, because it represents common ground between atomism and his opposition. The primary target of the mereological argument is *process extensionalism*, specifically the model defended by Dainton

(2000, 2008).⁵⁹ Recall from Ch.1, process extensionalism holds that an experience of a temporally extended event consists in an extended experiential processes with intrinsic temporal structure: (a) composed of temporally contiguous experiences of temporal parts of the events, (b) in virtue of being an extended process, an experience represents the temporal structure of dynamic events occurring within the same brief interval that the experience itself seems to take up. Since experience mirrors the temporal structure of events, for process extensionalism, if the event being perceived has temporal parts, then the extended process of perception also has temporal parts. So, as Chuard points out, process extensionalism is already committed to the first premise of the Mereological Argument:

M1) “Temporally extended whole experiences are mereologically composed by their temporal parts arranged successively.” (2011: 14)

While seemingly uncontroversial, the first premise is crucial to setting-up the argument, because it frames the ontological debate between atomism and process extensionalism in terms of the mereology of experiences. Since both views accept that there are brief temporal parts which compose relevant wholes, the disagreement focuses on what exactly they compose and whether or not the wholes are reducible to the parts. On one hand, atomism contends that temporally extended whole experiences are nothing over and above the temporal parts, since the wholes are mere successions of very brief experiences. On the other, process extensionalism claims that the temporally extended whole experiences are irreducible to the temporal parts.

Chuard states process extensionalism’s irreducibility commitment in terms of a failure of supervenience:

⁵⁹ Chuard calls the view ‘State temporal extension (STE),’ but that is merely a terminological difference, because his label picks out the same set of models as my label, ‘Process Extensionalism,’ which I also mention in Ch.1, fn19.

M2) “Temporally extended whole experiences don’t supervene on mere successions of their temporal parts.” (2011: 15)

Temporally extended whole experiences fail to supervene on mere successions of their temporal parts, if it is possible for two whole experiences E_1 and E_2 to share the same succession of temporal parts and yet $E_1 \neq E_2$. In other words, a particular succession of temporal parts composing a temporally extended whole experience E does not suffice to necessitate E , since the whole is not reducible to its parts. With this commitment of irreducibility, the burden falls on process extensionalism to provide the specific ontological difference between mere successions of temporal parts and the whole experiences which they compose.

M3) If so, “there must be some property F (or set thereof) that whole experiences instantiate but mere successions of their parts lack, the having of which doesn’t supervene on properties of these temporal parts arranged successively.” (2011: 15)

If there is a failure of supervenience between temporally extended experiences and mere successions of their temporal parts, then there must be one or more identifiable properties that extended whole experiences instantiate independently of their parts. This is the challenge that Chuard directs at process extensionalism: provide a property F instantiated by temporally extended experience E that is not grounded in E ’s temporal parts arranged successively. He critically evaluates a variety of putative candidate properties, including the phenomenological difference of ‘co-consciousness’ (Dainton 2000, 2008), the mereological differences of whole-part determination and part-part determination (Dainton 2000:188-206), and modal differences (Tye 2003: 29). In each case, Chuard (2011: 16-26) presents compelling objections that each of the candidate strategies fails to provide a property, or set thereof, that ontologically distinguishes

extended experiences from their temporal parts arranged successively. Thus, he concludes the mereological argument:

M4) “There is no such property F.” (2011: 15)

M5) So, it must be false that whole experiences do not supervene on their temporal parts.

I will not rehearse his arguments for (M4) here because a) I do not defend process extensionalism, and b) I argue that content extensionalism is immune to the mereological argument.⁶⁰ I do suggest a possible modal objection to (M4), in §2.3.2 below, but primarily in the context of developing a different explanatory challenge to atomism. I emphasize that the target of the argument is process extensionalism, because content extensionalism rejects (M1). Since content extensionalism does not share the mereological conception of perceptual experiences, there is no commitment to denying supervenience and no need to propose a candidate property F to make (M3) true.

How is (M1) false? Wasn’t it simply derived from a basic content principle for individuating perceptual experiences? The content principle is not the source of the problem, rather it is the implicit way in which perceptual experience is conceived in (M1) which presupposes mereological composition. Recall that content extensionalism claims that an experience of temporally extended events consists in a perception representing a temporally structured interval (see §1.3.2). There is no commitment that perceptions representing temporally extended contents are mereologically composed of temporal parts that are distinct experiences in their own right. Content extensionalism does not deny that some perceptions represent very brief near-instantaneous events; those are certainly one type of temporal experience with a particular type of representational content, but

⁶⁰ Chuard acknowledges that his argument is tailored to challenge only one family of extensionalist models, “Here, to repeat, I develop a version of the argument specifically targeting the state view (STE)” (2011: 12).

temporally extended experiences are another type. Suppose, for example, I hear a melody modulate from D major (IV) to C major (III) over a 3s interval, according to content extensionalism, the representational content of that experience includes the duration over which the modulation occurs and the change in key over that duration. By contrast, a very brief experience of hearing one note played in D major (IV) has a different representational content, lacking any representation of change or duration. By the content principle, these are tokens of two different types of perceptual experience.

The obvious atomist retort is to claim that the purported perception of melodic modulation is composed of several brief perceptions arranged successively, and the judgment of duration is a distinct post-perceptual representation aided by memory. First, this move begs the question, because it presupposes the atomist thesis that we cannot perceive temporal relations between distinct events, which is the central point of the disagreement. Second, it attempts to save the phenomenon of hearing the modulation over that interval, by appealing to underspecified post-perceptual cognitive processes that generate the seeming perception of duration that somehow is not really a “perception.” I address this error theoretic character of atomism at length in §2.3, so flagging it now is sufficient.

Additionally, an atomist might argue that since my purported temporally extended experiences represent events with earlier and later temporal parts, those experiences also have temporal parts. If so, then the parts of the experience representing earlier and later parts of the extended event are distinct experiences. To respond, let us revisit the modulation example. When I have the auditory experience of hearing a tonic modulation from D major (IV) to C major (III) over a 3s interval, the content of my perceptual representation includes a chord in D major (IV) before a common chord shared by both keys (e.g. E minor) followed by a chord in C major (III). My perceptual experience

represents the chords, the change in tonal center, and the relationship between the chords which constitute that change, including the temporal order in which the chords are played. An experience's representational content can be complex in a variety of ways, and it just so happens that part of the complexity of extended experiences involves the representation of temporal relations, but that does not entail that every part of a representation is its own experience.

Consider the non-temporal example of seeing the butterfly 3cm from the zinnia @ t1. The representational content of my visual experience includes the butterfly, the zinnia, spatial relationships between the two, not to mention the colors, shapes, and parts constituting both the butterfly and the zinnia. Is my perceptual experience of the antennae distinct from my experience of the proboscis? Is my visual experience of each of the petals of the zinnia its own distinct experience? Is my experience of the right-half of my visual field a distinct experience from that of the left-half? One could divide up one's visual field an infinite number of ways. If so, am I having infinite experiences every time I see anything? This sounds absurd, because it is. The atomist's suggestion that because my perception represents temporal parts of an event, those parts of the representation are themselves experiences, implies an infinite explosion of experiences for every possible experience, if the atomist's proposed criterion applied to parts of representations in general. If the criterion is only meant to apply to temporal parts, then it is objectionably arbitrary. Atomism then faces its own challenge of providing a candidate property F (or set thereof), that representations of temporal parts instantiate but representations of every other possible type of part lacks, the having of which entails the individuation of experiences for temporal parts and not others. The prospects do not seem promising, which is likely why the mereological argument makes no effort to attack content extensionalism.

In this section I have reconstructed Chuard's mereological argument, highlighted the commitment to a mereological conception of experience for both atomism and process extensionalism, shown how the argument poses a formidable threat to process extensionalism, and argued that content extensionalism is immune from this atomist attack. In the next section, I go on the offensive and present arguments against atomism and in favor of content extensionalism.

2.3. Arguments for Content Extensionalism

2.3.1. Apparent Phenomenology of Seeing Constant Motion

I began this chapter with several observations about the wide-ranging everyday phenomena that exemplify putative experiences of constant motion. Humans commonly report seeing bees pollinating flowers, snakes slithering, raptors gliding on thermal lifts, snowflakes falling, athletes running, records rotating on turntables, etc. Recall that for present purposes, seeing constant motion is the visual experience of a moving target continuously changing position, i.e. seeing the motion of an object between two stops. It bears repeating that constant motion in this sense neither implies constant direction nor constant velocity; insofar as the objects do not appear to stop during the periods over which they move, they satisfy the criterion for observable constant motions.

Besides the apparent phenomenological evidence that we observe countless examples of constant motion, many of our daily activities are premised on our capacity to detect and track moving objects. Swatting a nuisance housefly or mosquito would be nearly impossible, if one were unable to see the fast invertebrate motion in flight. Any sporting activity involving passing, catching, hitting, or volleying a ball would be unplayable, if one were unable to perceive motion and visually estimate trajectories to some degree of accuracy. Riding a bicycle on roadways would be a potentially deadly nightmare, if one were unable to see the motion of other vehicles,

pedestrians crossing, other cyclists, or animals crossing one's path. The prevalence of constant motions, the overwhelming introspective evidence that one cannot help but observe objects in motion, and the common daily activities dependent on perceiving motion serve as strong *prima facie* reasons for contending that the experiences of constant motion are not merely putative, but most are veridical.⁶¹ Call this the 'apparent phenomenology premise' for the *prima facie* argument that humans perceive constant motion.

Note that the apparent phenomenology does not yet settle how such seeing works, only that observation, introspective reports, and capacities for interacting with moving objects favor the strong general presumption that humans see things move. Accordingly, a theory that denies perception of motion requires a compelling error theory to explain away why it so strongly appears that we do perceive motion. Before examining the atomist's proposed error theory in greater detail, in the next subsection, I suggest that neuroscientific research programs investigating vision and skilled capacities for interacting with moving objects also operate on the premise that humans and other animals possess visual capacities to see constant motion.

2.3.2. Seeing Constant Motion in Neurocognitive Research

Our visual capacity to target and track moving objects is often taken as an uncontroversial and obvious fact about human experience, not just among the folk but also in relevant scientific circles. For instance, the experimental psychology literature on how skilled batters in fast ball-sports like baseball, cricket, and tennis successfully perform interceptive actions (Land & McLeod 2000,

⁶¹ Of course, there are well-known experimental paradigms that elicit visual illusions of apparent motion. For example, experiments where participants are presented two brief transient stimuli (e.g. colored dots on a screen) in two different locations, but report an impression of motion (Kolers 1973, Kolers & von Grunau 1976, Liu et al. 2004, Muckli et al. 2005, Larson et al. 2006) for philosophical discussion of those illusions (cf. Goodman 1978, Dennett 1991, Dennett & Kinsbourne 1992, Grush 2005a, Dainton 2008, Paul 2010, Hoerl 2015).

Sutton 2007, Croft et al. 2010, Hayhoe et al. 2012, Mann et al. 2013) do not question whether we are able to perceive objects in motion, despite disagreements between competing models over how exactly we do so. Instead the debates focus on alternative hypotheses explaining how we execute visual-motor control in the performance of skilled interceptive actions. Although competing models postulate differing functional roles for eye movement strategies like predictive saccades (cf. Land & McLeod 2000 and Mann et al. 2013), they agree that humans perceive objects in motion and seek to explain how that functions in the skilled performance of hitting a ball.

Additionally, the capacity for seeing constant motion is commonly attributed to other species and spawns research on how such seeing functions in those species: studies on how dogs track and catch frisbees (Schaffer et al. 2004), how dragonflies target and intercept prey midair at a 95% success rate (Olberg 2012, Gonzalez-Bellido et al. 2013), how archer fish determine where to catch their dislodged prey (Rossel et al. 2002, Wöhl & Schuster 2006), how falcons pursue prey using visual cues (Kane and Zamani 2014), etc. Of course, the fact that scientists attribute capacities for motion perception to both human and non-human animals does not settle the matter. After all, philosophers are experts in drawing subtle distinctions and challenging widely accepted beliefs, even those that shape and inform empirical research. Citing the wide variety of cutting edge research that posits the capacity to see constant motion does, however, flag the degree to which the atomist error theory departs from both common phenomenology and scientific orthodoxy regarding motion perception. To further press this point, I will explore an extended example to illustrate how atomism's denial of motion perception and mereological conception of experience are in tension with science operating on the presupposition that humans perceive motion.

There is confirmatory neurobiological evidence and reasonably strong consensus supporting the hypothesis that visual motion information is processed by neurons, located in the middle

temporal area of the visual cortex known as ‘MT’ or ‘V5,’ responding selectively to motion from different directions (Schenk 1997, Vaina et al. 2001, Schenk et al. 2005). Insult or damage to MT causes a condition known as *cerebral akinetopsia*, wherein the patient exhibits deficits in global motion perception ranging from stroboscopic vision to the inability to detect any motion in the visual field (Zeki 1991, 2015).

The most documented case of akinetopsia is LM, a middle-aged German woman whose MT was damaged by stroke (Zihl et al. 1983, Baker et al. 1991). LM could see colors, identify objects, and judge distance within normal ranges, however, lacking the capacity to see motion, she struggled with many daily activities. When attempting to cross the street, cars did not appear to move, rather cars first appearing far away would suddenly appear in front of her. She was unable to pour tea into a cup because she could not see the motion of the rising liquid; the cup would appear empty at one moment and overflowing the next. LM’s tragic condition provides further support for the earlier claim that normal human activities rely on motion perception, since her severe deficits resulted in an inability to perform such activities. LM’s visual experience is atomistic, but radically different from the visual experience of humans without structural damage to MT. It would be a considerable loss for atomism, if the model only applied to a small number of individuals with serious brain injuries inhibiting the perception of motion.

The case of LM poses no trouble for content extensionalism, since the model includes the hypothesis that seeing motion involves sampling visual information about an object’s trajectory over multiple temporal scales. If populations of neurons in MT selectively respond to motion from different directions, tracking objects’ change of relative position, then those neurons are sampling visual information over temporal intervals long enough to detect change of position over successive moments, on the scale of hundreds of milliseconds. By contrast, populations of neurons

in the primary visual cortex (V1) selectively respond to luminescence and contrast in the visual field, in order to detect the boundaries of objects (Marr 1982, Bar & Biederman 1999, Biederman 2013), such neural populations sample visual information over briefer intervals on the scale of tens of milliseconds to detect brightness values at a time. LM could see stationary objects and their boundaries, because her V1 was undamaged and able to sample static visual information at a time. By contrast, she couldn't see motion, due to the insult she suffered to MT, the cortical region that functions to sample extended visual stimuli like change of position over time. Content extensionalism thereby provides a plausible explanation of why LM could see objects at a time and judge spatial distances within normal ranges, but failed to see objects in motion.

Atomism appears to be at a slight disadvantage in explaining the case of LM, given the mereological claim that putative experiences *as of* motion reduce to a series of successive perceptions. LM was able to perceive objects at a time, atomic visual perception, but she did not undergo experiences *as of* motion. If putative experiences *as of* motion supervene on mere successions of their temporal parts (i.e. atomic visual perceptions), as the atomist claims, then it is puzzling how LM could experience atomic visual perceptions in succession without thereby undergoing an experience *as of* motion. She saw the temporal parts of objects at successive locations without having the putative whole experience of motion, which seems at odds with the atomist's mereological conception of experience. In response to the case of LM, atomists committed to denying that humans perceive motion and proposing an error theory have two likely strategies: a) challenge the standard interpretation that processing in MT ever constitutes motion perception, instead hypothesizing that it serves a post-perceptual role in generating visual representations, or b) suggest that structural damage to MT causes information loss, such that some

of the successive temporal parts (i.e. atomic perceptions) are inaccessible and without which no putative whole experience of motion supervenes, call this the ‘missing parts’ strategy.

On strategy (a), an atomist contends that MT processing is a downstream consumer of static perceptual information functioning to collate successive atomic perceptions, which makes possible representations of motions over time. On this story, the MT neurons are in the business of post-production editing and compilation, so an MT malfunction would result in the incapacity to represent a series of atomic snapshots of an object in adjacent locations *as* a moving object. According to this atomist reimagining of MT’s role in visual cognition, in the case of LM, damage to MT results in post-perceptual cognitive deficits in her capacity to represent motion, but not her visual perception. This treats LM as a limiting case for all putative experiences of constant motion. Most humans undergo experiences *as of* motion, because processing in MT enables representation of motion by combining successive series of static visual perceptions, but no one perceives motion, strictly speaking. LM’s deficits are representational, not perceptual. She perceives visually at any given time, but cannot generate the higher-order representations that constitute experiences *as of* motion over time.

Strategy (a) attempts to explain the LM case, by reassigning the function of the MT region while preserving the atomist commitment to denying motion perception. Nonetheless, the post-perceptual malfunction strategy has two apparent shortcomings. The first problem is that the explanation threatens to reduce the disagreement to a matter of semantics, a demarcation problem between what counts as ‘perception’ and what does not.

Extensionalists and neuropsychologists alike identify the seeing of motion as a perceptual phenomenon and assign functional roles to the neural processing in the visual cortex in their models, in order to explain how one perceives motion. If the atomist denies that we ever *perceive*

motion, but accepts that MT plays a critical role in the generation of representations constituting experiences *as of* motion, then it threatens to collapse into a merely verbal debate over the application conditions for the concept [perception]. Atomists contend that insofar as different takes on their claim that we cannot perceive temporal relations between non-simultaneous events, “rely on different notions of ‘perception’ (a narrower one restricted to the purely sensory vs a broader notion that’s not so restricted), the difference need not be all that substantive, however” (Chuard 2011: 8 fn.19). I concur that the dispute between atomists and extensionalists does extend beyond semantics, since whether or not we call experiences *as of* motion ‘perceptual,’ the two models propose competing explanatory hypotheses with significantly different ontological commitments. So, I recommend that we table worries that the atomist is merely playing at a verbal game.

The second, and more glaring, problem for strategy (a) is that it does not obviously answer the challenge that LM represents a supervenience failure for the atomist’s mereological conception of experience with which we began. If LM sees a stationary object at adjacent locations in succession, then why does she fail to undergo a putative experience of motion? After all, the atomist asserts that a putative experience of motion or succession is nothing over and above a succession of discrete experiences. If the malfunction in MT causes the failure to represent motion (perceptually or not), then it appears that putative whole experiences do not merely supervene on series of successive atomic perceptions, rather putative experiences of motion are independent representations produced via collation/compilation/integration of perceptual information in a particular order. On this picture, atomic perceptions $e^1, e^2, e^3 \dots e^n$ of an object in distinct contiguous locations at times $t^1, t^2, t^3 \dots t^n$ do not stand in a part-to-whole relation with an experience E of that object in motion over a duration Δt , rather they stand in a relation more akin to that which obtains between raw ingredients and a prepared culinary dish.

To achieve a desired culinary result, ingredients in a recipe must be combined in particular proportions with specific techniques, sensitive to time, temperature, and application of force. For example, a croissant pastry instantiates properties over and above the properties of its simple ingredients (viz. milk, sugar, flour, yeast, butter and salt), since the flaky layered finished product is a result of laminating the dough, i.e. creating many thin layers of dough and butter by repeatedly rolling, folding, and chilling; if done imprecisely, by rushing the steps, or overheating the dough in between rolling and folding each layer the baker will fail to yield a proper croissant. The properties of the baked croissant might supervene on its many-layered parts, but the finished pastry's properties do not supervene on the properties of its raw ingredients. Likewise, on strategy (a), atomic perceptions at a time are analogous to the raw ingredients and the representation of motion over time is analogous to the prepared croissant where the processing in MT "laminates" the successive experiences together.⁶²

If the foregoing analogy is apt, then strategy (a) undermines atomism's commitment to a mereological conception of experience. Invoking a function along the lines of post-perceptual collation to explain experiences *as of* motion, and the failure to have such experiences in cases of malfunction like LM's, provides a modal objection to premise (M4) in Chuard's Mereological Argument, viz. that there is no property F, the having of which doesn't supervene on properties of these temporal parts arranged successively. *Being collated* supplies a *de re* modal property that the whole experience of motion *E* instantiates, since *E* could not exist as *E* without being collated. Being collated does not supervene on the properties of its temporal parts $e^1, e^2, e^3 \dots e^n$, which it is possible to experience successively without undergoing an experience of motion *E*, as evidenced

⁶² Processing in MT is a sufficient but unnecessary condition for the visual experience of motion, since multi-realizability of functional kinds entails that some other suitable physical mechanism could instantiate the functional role of collating discrete successive perceptions played by the neural activity in MT.

by subjects suffering from akinetopsia like LM. If it is possible to experience a series of atomic perceptions $e^1, e^2, e^3 \dots e^n$ of an object in distinct contiguous locations in succession without thereby undergoing the whole experience of motion E , then, by Leibniz's Law, E is not identical to the succession $e^1, e^2, e^3 \dots e^n$. In this manner, tracing the implications of strategy (a) threatens to defeat the reductive mereology at the foundation of atomism.

To avoid the self-defeating implications of (a), atomists can turn to strategy (b) to explain the case of LM, hypothesizing that structural damage to MT causes information loss, such that some of the successive temporal parts (i.e. atomic perceptions) are inaccessible and without which no putative whole experience of motion supervenes. This route suggests that LM's failure to undergo experiences *as of* motion is simply a matter of missing temporal parts. The atomist can concede that LM perceives the object in contiguous locations at successive times as a result of the well-functioning regions of her visual cortex, and postulate that MT activation plays a functional role in the maintenance of content in visual short-term memory (VSTM).⁶³ If so, then structural damage to MT causes a failure to retain atomic perceptions in VSTM. Lacking an accessible series of retained atomic perceptions, LM cannot undergo experiences *as of* motion.

Strategy (b) is also consonant with the general appeal to memory, common in atomist error theories, explaining how we seem to experience motion despite the claim that we lack the capacity to perceive temporal relations between distinct events. Atomism holds that we can only perceive what happens at a given time, but given that we seem to undergo dynamic experiences like those of constant motion, memory functions to retain the just-past sensations which in combination with the present perceptual information yields a higher-order representation of motion.

⁶³ There is considerable neuroscientific support for the functional relationship between V5/MT and VSTM; see Bisley & Pasternack (2000), Bisley et al. (2004), Silvanto & Cattaneo (2010), Ainja et al. (2015), D'Esposito & Postle (2015).

In this vein, Thomas Reid argues that the folk (whom he calls ‘the vulgar’) speak loosely when they claim to “see” motion, “since no kind of *succession* can be an object of either the senses of consciousness; because the operations of both are confined to the present point of time” (1855: 235). Reid is clearly within the atomist tradition by denying the possibility of perceiving any kind of succession. He diagnoses that the reason folk report having experiences *as of* motion is that they do not properly distinguish sensation from memory. He proceeds to articulate the role that memory plays in discerning motion, “philosophically speaking, it is only by the *aid of memory* that we discern motion, or any succession whatsoever. We see the present place of the body; we remember the successive advance it made to that place: the first can, then, only give us a conception of motion, when joined to the last” (1855: 237). Given the critical role assigned to memory within atomist models, the missing parts strategy for explaining LM’s neuropathology seems plausible. If she lacks the ability to retain the just-past locations of a moving body, because of the damage to her MT, then she lacks the ability to generate an experience of *as of* motion via successive combination of temporal snapshots.

The missing parts strategy appears to cohere with the atomist’s mereological conception of experience, since it attempts to preserve the idea that a temporally extended experience *as of* succession supervenes on a succession of experiences. If there are missing temporal parts due to a deficit in VSTM, in cases of akinetopsia, then there are no atomic experiences arranged successively upon which an experience *as of* succession supervenes. Or, is there? By all accounts, LM does perceive objects in contiguous locations at successive times as a result of the well-functioning regions of her visual cortex, but *ex hypothesi* she is unable to retain any short term memory of the discrete visual experiences. So, LM does have successions of discrete experiences, yet no supervening experiences *as of* succession. The atomist’s suggestion is that she lacks the

capacity to retain memories of the just-past experiences, and thus the missing temporal parts in her memory prevent experiences *as of* motion.

There is reason to be suspicious of the missing parts explanation. First, LM has the succession of experiences, but either does not retain a memory of each experience in succession or cannot access such memories. Nevertheless, atomism claims that experiences *as of* succession are nothing over and above successions of their temporal parts. The missing parts solution sneaks in the tacit assumption that short-term memories of an experience are identical to the experiential temporal part, since that is what LM is missing according to this strategy. Memories represent experiences, but representation falls short of identity, which makes the atomist's assumption dubious at best and at odds with standard models of memory encoding. Without the assumption, supervenience fails and the missing parts strategy undermines atomism's commitment to a mereological conception of experience. So, option (b) does not fare much better than strategy (a), and atomism lacks a satisfactory explanation of LM that preserves the central commitments of the model.

To take stock of the arguments in the preceding sections: I first challenged atomism by defending the apparent phenomenology premise, viz. that the prevalence of constant motions, the overwhelming introspective evidence that one cannot help but observe objects in motion, and the common daily activities dependent on perceiving motion serve as strong *prima facie* reasons for contending that the experiences of constant motion are not merely putative, but most are veridical. Second, I surveyed a wide variety of recent neurocognitive research that posits the capacity to see constant motion in both humans and non-human animals, in order to further emphasize the degree to which the atomist error theory departs from both common phenomenology and scientific orthodoxy regarding motion perception. Lastly, I employed the case study of LM's cerebral akinetopsia to develop an argument that atomism has insufficient resources to explain LM's

neuropathology without undermining central commitments of the model. I argue that content extensionalism accounts for the apparent phenomenology, coheres with presuppositions of ongoing neurocognitive research, and provides a plausible explanation of LM's inability to perceive constant motion. Presenting this extended challenge to atomism, I now turn to the atomist error theory that aims to explain away the apparent phenomenology and the presumption that humans perceive constant motion.

2.3.3. Atomism's Error Theory relies on the Zoetropic Effect

Atomism denies that we perceive constant motion but offers an error theory for the phenomenal seeming of such putative experiences, whereas content extensionalism explains how we perceive constant motion by representing properties and relations instantiated by non-simultaneous events.

According to atomism, putative temporal experiences *as of* a baseball in motion or *as of* a guitar arpeggio, are a result of some cognitive post-processing, often involving working memory, that utilizes the series of atomistic sensory “snapshots” captured at each moment. On this construal, the central claim of atomism is that perception is momentary, and mental representations of dynamic events are not perceptual—although atomistic percepts provide the experiential input for constructing representations of dynamic content. In this way, atomistic perceptions are the sensory building blocks extracted and summated to generate the temporally extended representations, which generate putative dynamic content in the phenomenology of our experiences. So, although atomists deny that humans perceive constant motion, they acknowledge the need to account for

the phenomenology of constant motion in visual experience and do so by a broad appeal to the zoetrope effect.⁶⁴

The *zoetrope effect* is whenever a sequence of static images are presented in a manner that creates an illusion of motion. A zoetrope is an early animation device consisting of a cylinder with a sequence of related static images affixed to the inner ring of the drum and thin slits in the cylinder, invented by William George Horner in 1834. The images on the inner ring might, for example, represent horse figures in different positions of a gallop, like those in Muybridge's (1887) animal locomotion studies.⁶⁵ Although each individual image in the sequence lacks any dynamic depictive content, the zoetrope produces an illusion of motion when the cylinder spins causing an observer peering through the slits to perceive a "moving" image (e.g. a single horse figure galloping). The slits keep the successive images from blurring together. On most accounts, the experience is illusory, because instead of perceiving a series of similar horses, the viewer perceives a single horse galloping.

Notice that, in addition to a series of images with a high degree of overlap in the representational content, a zoetrope requires actual motion of the drum to produce the illusion of motion. A simple flip-book animation works on the same principle, but it is the actual motion of flipping pages depicting a sequence of events which creates the illusion of motion in the animation. Likewise, the advent of motion pictures and cinematography derives from mechanisms designed to produce a zoetrope effect, like Emile Reynaud's praxinoscope (1877) that utilizes mirrors,

⁶⁴ Ian Phillips (2011) refers to the atomistic model of perception, as the 'zoetrope conception of experience.'

⁶⁵ See the complete catalogue of photographs and original prospectus from his locomotion studies: Muybridge, Eadweard (1979). *Muybridge's Complete Human and Animal Locomotion: All 781 Plates from the 1887 "Animal Locomotion."* Dover Publications.

instead of slits on the outside cylinder, and Thomas Edison & W.L.K. Dickson's kinetograph camera and kinoscope viewing box (1891).⁶⁶

The zoetrope effect provides a compelling metaphor for explaining the atomist model of temporal perception. Just as animation cells are used in stop-motion animation, or frames of stills compose a film, the atomist argues, so too our perceptual system uses a series of static inputs at successive times to represent a dynamic event occurring over time. It is tempting to think of visual perception as exploiting the zoetrope effect, since motion picture is a familiar medium, making the atomistic explanation intuitively plausible and effective as a heuristic. The appeal to cinematic motion is all too common and many atomists embrace this metaphor as a way to motivate the possibility that our perceptual systems work in a similar fashion (cf. Chuard 2011, Paul 2010). If we can record and reproduce action on film via a series of static images, then it is possible for a visual system to operate similarly by "recording" the static retinal image at each successive time, summing the series of static images, and thereby generating a visual experience *as of* constant motion.

When I seem to visually experience a butterfly flying from one flower to another, I do not perceive the butterfly in motion, according to atomism, rather I perceive the butterfly in just noticeably different positions at successive contiguous locations at successive times and additional cognitive processes utilize these static images to make it seem as though I see the butterfly in motion. When I record a video of the butterfly pollinating zinnias with the digital camera built into my phone, the camera records at a rate of 30 frames per second (fps), i.e. it progressively scans

⁶⁶ For a classic history of scientific film, see Tosi, Virgilio. (2005) *Cinema Before Cinema: The Origins of Scientific Cinematography*. Translated by Sergio Angelini. British Universities Film & Video Council. For more on Edison's inventions, "Thomas Edison Papers," archive at Rutgers catalogues all of Edison's patent applications and dates related to the inventing and patenting process, including those related to motion picture: <http://edison.rutgers.edu/filmpats.htm>

and encodes a orthogonal bitmap digital image once every ~33ms (1/30 second) (Poynton 2012). The resulting digital video of the butterfly in motion is composed of a series of static images shown in rapid succession at a constant rate; each digital image in the series represents the butterfly and the zinnias over a very brief 33ms interval, and when the series is displayed in rapid succession the butterfly's busy pollinating motion can be viewed on a digital screen.⁶⁷ Like earlier technologies that exploit the zoetrope effect, basics of digital video are easy to understand and it enables one to conceive of a possible system of visual perception that functions in an analogous manner, scanning and encoding retinal images at a constant rapid frame rate, enabling both our experiences of constant motion and our memories thereof. Digital video reduces to a series of orthogonal bitmap digital images, likewise, the atomist contends that putative visual experiences of constant motion reduce to a series of static visual perceptions arranged successively.

The zoetrope cinematic motion analogy reinforces ontological commitments of the atomist model. The analogy supports the reductive claim that putative temporal experiences of motion, succession, change, and duration reduce to mere successions of static perceptions at a time. Experiences are atomistic like frames of a motion picture, and putative experiences representing dynamic content over longer durations are nothing over and above the series of static experiences. As Chuard avows, “atomists insist that we cannot really perceive such relations, on the ground that no experience or experiential content is temporally extended enough to represent temporally distinct events” (2011: 3). Although atomistic experiences are brief enough that they cannot represent relations between non-simultaneous events, experience need not be durationless. In the video analogy, the digital camera at a rate 30 fps scans an image once every ~33ms, and higher frame frequencies further shorten the interval between scans (e.g. 48 fps = one scan every

⁶⁷ [Follow this link to view a 4 sec. digital video I shot of a butterfly pollinating a zinnia.](#)

~20.8ms). Likewise, on the atomist model, visual perception operates at a high frame rate, because the content in a single experience is not “extended enough” to represent relations between non-simultaneous events. In this respect, atomism appears committed to a fixed high frequency sampling rate, whereas extensionalism posits multi-scale sampling.

The cinematic zoetrope analogy also provides a useful framework for explaining the atomistic error theory for why we seem to have temporally extended experiences even though, strictly speaking, we do not. For atomism, the apparent phenomenology of putative temporal experiences are a function of i) phenomenal similarity—the “successive combination” of the phenomenal properties in each experience in the succession, ii) temporal proximity: the external temporal relations between the experiences, iii) the “degree of overlap” between the representational contents of the experiences, and iv) various contingent limitations: cognitive, mnemonic, introspective (Chuard 2011: 17).

When I seem to see the butterfly’s motion as it pollinates, the illusion of experiencing constant motion results, in part, from the high frequency sampling rate, i.e. the close temporal proximity between each atomistic visual perception. If the visual system had a slow frame frequency with longer intervals between each perception, then one’s visual experience might seem staccato and discontinuous, like a strobe-light effect. Also, each visual perception in succession, like the bitmap digital images, has a high degree of representational overlap and phenomenal similarity. Besides the moving butterfly and flowers disturbed by the pollination, nearly everything else represented in the background visual field remains relatively unchanged from one atomistic perception to the next. Successive perceptions in the series represent the butterfly in just noticeably different positions at successive contiguous locations at successive times, but there is still a very high degree of representational overlap, especially if the interval between each perception is very brief and one

undergoes 30 or more distinct visual experiences per second. The apparent smooth and phenomenally continuous visual experience I seem to undergo as I observe the butterfly pollinating is due to the phenomenal similarity of each successive experience and high degree of representational overlap between the representational contents. If one were to splice together a series of digital images with different kinds of butterflies pollinating distinct kinds of flowers in varying environments, the playback would resemble a slideshow or an odd montage, but would not generate the illusion of a single butterfly in constant motion, because of the low degree of representational overlap and phenomenal similarity.

There are also contingent limitations of the system that realizes visual perception. These include various noticeability thresholds, such that some small gradual changes will go unnoticed in introspection. Nevertheless, the cognitive, mnemonic, and introspective limitations of perceptual systems are acknowledged on both sides of the debate, and thereby should not play a central role in motivating or distinguishing atomism over and against extensionalism.⁶⁸

Appeals to the zoetrope effect and cinematic motion metaphor, central to the atomist's error theory, pump folk intuitions and make the theory pre-critically attractive, but it is also misleading. First, the visual metaphor does not translate well for other modalities like audition, proprioception, and olfaction, nor does the atomistic conception of experience provide a satisfying account of the multi-modal perceptions and the discrepancies in various sampling rates for distinct sensory modalities. As I detail above, a plausible case can be made for vision to function like a high frequency frame rate digital video, but the metaphor is inadequate for other sensory modalities. For instance, the targets of auditory perception, including melodies and spoken sentences, are

⁶⁸ See Chapter 4, in which I delimit the lower-bound thresholds on interval processing and integration for temporal perception in detail.

extended in time. Hearing a melodic phrase is not reducible to hearing individual notes in a particular order. Sounds are events, which produce signals that transmit information carried by sound waves (Bowen 2013) and hearing the dynamic signal cannot be reduced to hearing discrete parts of the sound envelope in succession. Perceiving a tonal modulation requires hearing the relationships between the non-simultaneous chords. In addition, our sound engineering and musical production does not mirror the frame rate model of digital video.

Second, the guiding metaphor conceives of perception as a passive recording process, continuously scanning sensory images of the world at a constant rate. This passive conception is at odds with active prospective models of perception on which our experiences are driven by internal representations and actively constructed by probabilistic predictions and trajectory estimations (Gregory 1997, Grush 2005a, Eliassmith 2007, Howhy 2007, Friston 2002, Friston 2005, Friston & Stephan 2007, Friston et al. 2012). “The basic idea is very simple: the posterior probability of a given hypothesis about the causes of one’s sensory input will go up if predictions of future input based on that hypothesis are correct. This could be the method by which the brain gets to represent the world in spite of the noise in the sensory channels and the context-sensitivity of the causes in the sensorium (such as, e.g., occlusion). This means that the brain doesn’t try to infer the causes from the effects (the sensory input) but rather predicts the effects (the input) from a model of their causes” (Howhy 2007: 322). By contrast, on the atomistic model, experience is driven by brief sensory inputs continuously scanned and summated, like digital video, which is incompatible with predictive representation-driven models of perception. Content extensionalism entails an active predictive model of perception, consonant with the multi-scale sampling hypothesis, whereas atomism is rooted in a passive receptive model of perception. In my estimation, this contrast provides another reason for preferring extensionalism over atomism.

2.3.4. The Individuation Argument

Phenomenological observations are important for describing the phenomena which require explanation, and, in this respect, serve to sharpen the focus of what theories of temporal perception intend to explain. The primary reason to shift away from the phenomenology is because atomists never deny that we have experiences *as of* motion, *as of* change, *as of* duration, etc., rather they offer an alternative explanation as to how such experiences are generated which is perfectly compatible with the atomist denial that we perceive temporal properties and relations between non-simultaneous events. Accordingly, an argument from the best explanation of the phenomenology is not very promising, since the opposing models both have explanations of the phenomenology and offer differing criteria for what counts as best—parochial conceptions of parsimony, simplicity, fecundity, phenomenal perspicuity, etc. While we cannot completely ignore the phenomenology of temporal experiences, we should recognize that there are multiple plausible explanations of the phenomena and additional arguments are required to make a case for the superiority of one over the other contenders. While I think the debate is better served by resisting the temptation to allow the apparent phenomenology to be the sole focus of the debate, it is instructive to first see how it results in a stalemate before shifting the focus to other arguments.

Traditional defenses of extensionalism, especially those models I identify as process extensionalism (see §1.3.1) place a great deal of weight on phenomenological claims about purported experiential differences between an experience of succession and a succession of experiences, notably emphasized by William James (1890: 692) and reiterated by many others.⁶⁹ Most agree that such a difference exists, underwritten by simple introspection on one's experience,

⁶⁹ Cf. Husserl (1897-1917: 12), Broad (1923: 351), Sellars (1968: 232), Gallagher (1998: 22), Dainton (2003: 2) & (2008: 623), Lockwood (2005: 363); for a dissenting opinion on the purported phenomenology, see Kelly (2005b).

but there is disagreement over what, if anything, to make of the putative phenomenological difference.

Broad (1923) and Russell (1927) both employ a simple analog clock example to illustrate that there is such a difference distinguishable between seeing the succession of the second hand on an analog clock, for instance, and having a succession of discrete minute hand experiences and thereby noticing that it has moved. In the first case, I seem to see the successive motion of the second hand, whereas, in the second case, I only infer or become aware of the motion of the minute hand by comparison of successive experiences. Along these lines, an argument is developed that purports to defend extensionalism and show that atomism fails to explain the difference between cases of perceptible and imperceptible motion.

There is a well-advertised type of difficulty in such cases as the analysis of a perceived motion. If I move my hand before my eyes from left to right, and attend to the visual percept, it seems qualitatively different from the successive perceptions of my hand in a number of different positions. On a watch, we can “see” the motion of the second hand, but not of the minute hand. There is no doubt that there is an occurrence which we naturally describe as the perception of motion. We are aware of perceiving a process: if I move my hand from left to right, the impression is different from what it is if I move my hand from right to left, and it is obvious to everyone that the difference is in the “sense” of the motion. We can, in fact, distinguish earlier and later parts of the motion, so that the motion does not appear to be without structure. But the parts of it seem to be other motions, which, presumably, must each have its own structure. (Russell 1927: 278-9)

Russell appeals to the qualitative difference between visually perceiving his hand moving and experiencing discrete successive perceptions of his hand in different locations, and affirms that the former type of experience without a doubt represents perception of motion. He also emphasizes that he is able to distinguish earlier and later parts of a motion, such that perceiving his hand move involves perceiving the structural relations of his hand’s successive location over time. The

following is a reconstruction of the so-called, ‘Individuation Argument,’ (cf. Broad 1923, Kiverstein 2010, Phillips 2011, Hoerl 2013):

- I1) I perceive the second hand moving.
- I2) I do not perceive the minute hand moving.
- I3) The salient difference between 1 & 2 is the length of the interval over which the changes occur. ($I2 > I1$)
- I4) If I perceive an object moving, then I perceive the structural relations of the object's successive locations over times. ('at-at' motion, see §2.4.2 below)
- I5) If I perceive the structural relations between an object's successive locations over times, then extended contents of visual experience can represent relations between non-simultaneous events.
- I6) If so, content extensionalism is true and atomism is false

Proponents of the Individuation Argument clearly lean heavily on the apparent phenomenology of motion perception to support the first two premises. I see the second hand on the analog clock moving, and I cannot see the minute hand moving. From the apparent phenomenological difference, it is inferred that there are perceptible motions and imperceptible motions, and there is a limit on the length of interval over which a motion occurs such that it is visually perceptible by humans.⁷⁰ If an object moves too slowly, then we cannot perceive its motion. Broad emphasizes this minimum rate of change in the following passage:

⁷⁰ One can extend this argument from qualitative difference by appealing to examples like Locke's cannonball in order to illustrate that some motions and changes occur too fast to be perceived. Some motions are too slow to be perceived, other motions are too fast to be perceived, and only a limited range of motions occur at perceptible rates of change. If so, then our visual acuity for motion perception has both upper-bound and lower-bound limitations. In Ch. 4, I survey these sensory limitations, which place constraints on models of temporal perception.

Thus the qualitative differences between its earlier and later sections will be sensed together; i.e. the observer will actually sense the changing and will not merely notice that something has changed. We can now see why a change must surpass a certain minimum speed if it is to be sensed as such. If a change takes place slowly, this means that closely adjacent events are qualitatively very little different from each other. It may therefore happen that two events are not qualitatively distinguishable by us unless they are separated by more than the duration of a Specious Present. If this be so, these two qualitatively distinguishable sections of a single long event are too far separated to be sensed together. (Broad, 1923: 352)

Broad is making two closely related points in this passage. First, there is a significant difference between the experience of perceiving change occur and merely recognizing that some change has occurred. Second, perceiving motion or change results from sensing together the qualitative differences between non-simultaneous events. Hence Broad opposes that atomist thesis that perception can only represent what happens at a given time, since he clearly asserts that we perceive relations between non-simultaneous events.

By relying on introspection and the apparent phenomenology, the Individuation Argument begs the question against atomism. There is no reason for an atomist to grant (I1), since atomism explicitly denies that we see constant motion, like the second hand moving. Revising the premise so that it doesn't presuppose the falsity of atomism we end up with:

(I1*) I *seem* to perceive the second hand moving.

The premise is no longer controversial, because all parties to the debate already agree that we seem to have experiences *as of* motion. With that adjustment, however, we must make corresponding revisions to (I4):

(I4*) If I *seem* to perceive an object moving, then I perceive the structural relations of the object's successive locations over times.

Revising the premise in this fashion makes it false, since seeming to perceive motion is not a sufficient condition for perceiving structural relations of the moving object's successive locations over time. Atomists can grant the truth of the antecedent, but deny the consequent, because they can offer a different explanation of why we seem to perceive an object moving. Thus, (I4*) is false and the Individuation Argument is unsound upon revision. One can certainly weaken the premise further to prevent its obvious falsehood:

(I4@) If I *seem* to perceive an object moving, then I *seem* to perceive the structural relations of the object's successive locations over times.

The atomist can grant that you seem to perceive such structural relations between an object at successive locations, and invoke the zeotropic effect in attempt to explain why we do not, strictly speaking, *perceive* those relations. This further revision does not help the extensionalist, because it requires a corresponding revision of premise (I5) rendering it vulnerable to objection, which ultimately blocks the inference to the conclusion:

(I5@) If I seem to perceive the structural relations between an object's successive locations over times, then extended contents of visual experience can represent relations between non-simultaneous events.

The atomist can obviously deny that seeming to perceive the structural relations between an object's successive locations is a sufficient condition for representing the relations between non-simultaneous events in visual perception. In brief, the deliverances of apparent phenomenology are not, by themselves, sufficient to establish the falsity of atomism and truth of extensionalism. As mentioned at the outset of this section, I do not find the Individuation Argument convincing, and I have now shown that it clearly fails to guarantee its overreaching conclusion.

2.4. Zeno-inspired Puzzle of Motion

In this section, I reconstruct a familiar Zeno-inspired puzzle of motion, survey two false solutions to the puzzle, and explain the now standard 'at-at' theory of motion solution (cf. Russell 1903; W.C. Salmon 1970, 1977, 1984). After doing so, I construct an analogous puzzle of motion perception and argue that the 'at-at' solution provides further support for *extensionalist* models of temporal perception, as opposed to atomist models. Revisiting proposed solutions to the familiar arrow puzzle serves to highlight how contemporary debates regarding motion perception bear striking analogues to the metaphysical disputes generated by Zeno's puzzle.

2.4.1. The Puzzle

Perceived motion has long been a source of puzzlement; at least since Zeno of Elea in 5th century BCE framed it as paradoxical in his efforts to defend a Parmenidean monism, such that "all is one" entails change and motion are illusions.⁷¹ Zeno asked us to imagine an arrow in flight, but to stick with one of my earlier examples, let us think about tracking a baseball in constant motion. Imagine a baseball thrown by a pitcher, or better yet, observe an actual baseball from the moment the pitcher releases the ball propelling it towards home plate to the moment it comes to rest in the catcher's mitt. What do we see? Surely, we see the baseball in motion; we see the baseball moving along a continuous path, typically with some angular rotation, until it hits the catcher's mitt or is redirected by a hitter's bat. Consulting the contents of our experience, it clearly seems as though we perceive the motion of a baseball in flight.

⁷¹ Our canonical record of Zeno's flying arrow paradox comes from Aristotle (*Physics*, VI 9.239b5-32). See W.C. Salmon (ed.) *Zeno's Paradoxes* (1970), for an excellent collection of philosophical and mathematical treatments, including contributions from Bergson (1911), Benacerraf, Black, Grünbaum, Russell (1929), and Thomson.

Now consider the skeptic's argument; someone like Zeno asks us to now imagine the baseball at any single instant along its path. Is the baseball moving at t_1 ? How about at t_2 , or t_3 , or t_n ? No, Zeno claims, at any time-slice along the baseball's trajectory, it is static and motionless. Thus, we arrive at an apparent puzzling contradiction:

Z1) From t_1 - t_n , the baseball *moves* from point A to point B.

Z2) At any given instant t_1 - t_n , the baseball is motionless on the path AB.

Z3) So, the baseball both moves and does not move. (Absurd!)

Of course, the paradox only arises if you grant Zeno's supposition that an interval of time is composed of indivisible instants.⁷² Zeno reasons that if the baseball moves from point A to point B throughout the period of his flight (from t_1 - t_n), then it moves at each instant of its trajectory. Being located at each consecutive instant during the period of its trajectory, the baseball occupies a space equal to its own volume. But, if the baseball occupies a space equal to its own volume at an instant, then it is not in motion at that instant. So, the baseball is not in motion at any instant within the period of its flight. Thus denying the consequent of the initial conditional, Zeno concludes that the baseball does not move at all, which undermines (Z1).

Note Zeno's presupposition, as Russell points out, "the view that a finite part of time consists of a finite series of successive instants seems to be assumed; at any rate the plausibility of the argument seems to depend upon supposing that there are consecutive instants" (1929: 137). At each instant, the baseball is located precisely in a space 'equal to itself,' and it cannot move during that instant; yet, at the next instant it occupies an adjacent location in space, and so on until the baseball comes to rest. The baseball changes position from one instant to the next, but at no instant

⁷² Aristotle denies this supposition, "Zeno argues fallaciously. For if, he says, everything is always at rest when it occupies a space equal to itself, while that which moves is always in the now, the moving arrow lacks motion. But this is false, since time is not composed of indivisible nows, just as no other magnitude is." (*Physics*, VI 9.239^b5-9)

is the baseball ever moving. Russell remarks that on Zeno's analysis the baseball's change of position is nothing short of 'miraculous,' since the change must occur at no time at all.

2.4.2. Proposed Solutions to the Puzzle: Zeno, Bergson, and Russell-Salmon

Zeno's proposed solution to the paradox is to simply reject the reality of motion: all perceived motion and change is an illusion; motion is not real. By denying (Z1), Zeno is committed to an error theory about all reports of "perceiving motion", and owes us an explanation of why we seem to experience things moving, if such experience is an illusion—analogous to the burden of explanation shouldered by atomism (see §2.3.3). I debate the possible merits of such an atomistic error theory above, finding it explanatorily inadequate. I likewise count the error theory as a cost of Zeno's strategy here. Besides the somewhat dubious assumption about time being composed of consecutive indivisible instants, commitment to a widespread error theory and the violence it does to our ordinary experiences of motion and change, should indicate that endorsing the unreality of motion and change is the wrong conclusion to draw from Zeno's puzzle.

Moreover, I contend that Zeno commits a fallacy of composition: first, he assumes that a motion is composed of consecutive indivisible instants; and, second, he infers that since the baseball is motionless at each instant along its path, the baseball must be motionless over the entire interval. Zeno's failed solution thus relies on an invalid inference from an observation about instantaneously located objects to the strong metaphysical conclusion that motion is unreal. Zeno is not alone, however, in trying to draw metaphysical conclusions from his paradoxes. Before looking at a promising solution to the puzzle, let us briefly consider another false start that draws an opposing metaphysical conclusion.

In a contrast to Zeno, Henri Bergson (1911) denies (Z2) by claiming that the actual motion of the baseball is not composed of motionless instants. He suggests that Zeno's mistake is to divide a motion into successive motionless locations, thereby being misled by what Bergson calls 'the cinematographic method' of representing reality. According to Bergson, the cinematographic method is the typical procedure for organizing our knowledge of physical processes, according to which we decompose a process by generating a series of successive state descriptions, analogous to the method in which motion pictures are created using a successive series of still frames. For instance, the atomist's error theory that invokes the zoetrope effect to explain away apparent motion perception exemplifies the cinematographic method. Bergson recognizes that this analytic method has some epistemic and practical advantages, but he contends that it fails as a guide to the metaphysics of motion and change.

He argues that a single motion is a simple and undivided process between two stops, i.e. a movement 'created in a single stroke.' For Bergson, the whole trajectory of a single motion is ontologically basic, revealed in intuition by 'entering into' the process and directly perceiving the phenomena of change and motion, and thus motionless states are mere artifacts of analysis decomposing motion into static points or spaces along its trajectory.⁷³ By decomposing a process into a series of motionless states, Zeno divides the single motion into multiple motions, by adding counterfactual stops along its path, i.e. locations where the baseball could possibly stop, but did

⁷³ Bergson championed intuition over analysis, in *An Introduction to Metaphysics* (1913: 7) he makes this methodological commitment explicit: "By intuition is meant the kind of *intellectual sympathy* by which one places oneself within an object in order to coincide with what is unique in it and consequently inexpressible. Analysis, on the contrary, is the operation that reduces the object to elements already known, that is, to elements both common to it and other objects. To analyze, therefore, is to express a thing as a function of something other than itself." He holds that analysis is complex, piecemeal, symbol-laden and an "always imperfect translation" of reality for practical epistemic goals, whereas "intuition, if intuition is possible, is a simple act" (1913: 8) and the true guide to metaphysics. I disagree with his reliance on metaphysical intuition and the concomitant criticism of analysis, but find merit in his insight that theoretical posits are often artifacts of one's chosen analytic methods. See Russell (1929, 1927) for extended critique of Bergson and defense of the alternative position that analysis is necessary for understanding motion and change, both the physical stimuli and our perceptions thereof.

not. Bergson argues that such analysis misrepresents the metaphysics of an inherently dynamic process, by depicting a motion as a series of motionless states. Additionally, he concludes that any attempt to recompose the whole movement from successive motionless states, will lead to Zeno's absurd conclusion that “movement is made of immobilities.”⁷⁴

It is important to note that Bergson's response to Zeno, makes a similar mistake, by implicitly ceding that Zeno's inference follows if one accepts the cinematographic representation of reality. That is, Bergson does not identify the fallacious part-to-whole inference made by Zeno, and implicitly makes the same error in his critique of Zeno (cf. Salmon 1970: 24). Bergson objects to the premise that the baseball is motionless at instantaneous locations along its path, by denying that a single motion has proper parts. Where Zeno concludes that motion must be unreal, Bergson concludes that the motionless instantaneous states must be unreal. Because Bergson holds that pure intuition is the proper guide to metaphysics and thinks reductive compositional analysis is misleading, he thereby places a stringent requirement on our understanding of change and motion: a dynamic process can only be understood through intuiting the nature of the structure given in direct perception.⁷⁵ So, a motion's structure is a single continuous process, which is revealed in the experience of perceptual continuity.

Bergson diagnoses the flaw in Zeno's argument to be the analytic decomposition of a continuous motion into a series of motionless states. By concluding that all such reductive analysis falsifies, Bergson throws out the baby with the bathwater, because he overlooks the possibility that analysis affords us the tools to understand a moving object's trajectory in terms of spatially

⁷⁴ Bergson (1911), reprinted in Salmon (1970: 63)

⁷⁵ “The view urged explicitly by Bergson, and implied in the doctrines of many philosophers, is, that a motion is something indivisible, not validly analysable into a series of states. This is part of a more general doctrine, which holds that analysis always falsifies, because the parts of a complex whole are different, as combined in that whole, from what they would otherwise be.” (Russell 1929: 119)

contiguous locations at consecutive times, preserving continuity and avoiding the conclusion that motion consists of immobilities. Once we recognize how such analysis can aid our understanding of physical motion, we arrive at a promising solution.

The widely accepted solution to the paradox invokes Bertrand Russell's 'at-at' theory of motion (1903, Ch. LIV), which claims that motion is simply occupying successive locations at successive times. Zeno fails to recognize that motion is a function of an object *at* distinct contiguous spatial locations *at* adjacent times. If the baseball is in exactly the same location at t_1 and at t_2 , then it is at rest and not moving. If, however, the baseball is at $\langle 2,3,4, t_1 \rangle$ and then at $\langle 2,4,5, t_2 \rangle$, then from t_1 to t_2 the baseball has moved one unit in the y,z direction of state space. Mathematical analysis enables us to describe the baseball's motion by a mathematical function that maps spatial values (x,y,z) onto each admissible value for t . Zeno is simply looking at each state of the baseball (i.e., each ordered quadruple) by itself, and concluding that there is no motion. Obviously, an object at a static spatio-temporal location is not moving, but the mistake rests in failing to see that motion only occurs over an interval, not at a single point in time. According to the At-At solution, motion "consists in being *at* particular points in space *at* corresponding moments. There is no *additional* question as to how the [baseball] *gets from* point *A* to point *B*; the answer has already been given – by being at the intervening points at the intervening moments" (Salmon 2012: 415). We can reconstruct the At-At response to Zeno's puzzle, as follows:

R1) Motion is simply occupying successive locations at successive times.

R2) For the baseball to have a velocity at time, t , is to be appropriately located at times immediately prior to and immediately following t .

R3) So, at t_4 , the baseball has an instantaneous state of motion in virtue of its locations at t_3 and t_5 .

R4) So, it is not the case that at any given instant t_1 - t_n , the baseball is motionless on the path AB. (Z2 is false)

With this improved solution to the puzzle in hand, and its corresponding theory of motion, let us return to the debate between competing models of constant motion perception. I think there are some insights to be gathered from examining some analogues between the Zeno's puzzle and the disagreement between atomism and content extensionalism. To begin, let us first revisit how both content extensionalism and atomism analyze a case of putative motion perception like seeing a baseball in motion.

Content extensionalism claims that I perceive the baseball move, e.g. when a pitcher throws a fastball, in virtue of visually representing the structural relations between the ball's successive locations at successive times. I visually target a moving object like a baseball by representing the intervening locations that it occupies over a brief interval. If so, then extended contents of visual experience can represent relations between non-simultaneous events. Content extensionalism entails that my perception of a dynamic target, like a moving baseball, encompasses a temporal field of content, i.e. a perceptual experience can represent successive events occurring over a brief temporally structured interval. Accordingly, if the At-At analysis of motion is correct, then content extensionalism provides a clear model of how perception of motion is possible.

By contrast, atomism claims that I do not perceive the baseball move, e.g. when a pitcher throws a fastball, rather I perceive the baseball at successive locations at successive times and judge that the ball is moving based on the present static perception and retained memories of the just past locations of the ball. At first blush, it appears that atomism also coheres with the At-At theory of motion, since I have discrete perceptions of the ball at successive locations at successive

times. Nevertheless, atomism denies that we perceive motion since we never represent successive locations of the ball in perception, but does not deny the apparent phenomenology.

The atomist can grant that we seem to perceive motions, successions, changes, etc., yet argue that such putative temporally extended perceptions are the result of have a series of atomistic perceptions realized in a particular order. I seem to see the ball in motion in virtue of actually perceiving the ball occupy spatially contiguous locations at successive times. Since one only perceives what happens at a given time according to atomism, I never perceive the ball moving, because doing so would require perception of the temporal relations between non-simultaneous events, viz. the non-simultaneous events of the ball occupying spatial locations at successive times. It follows from atomism that representations *as of* succession reduce to successive perceptions of finely individuated atomic events. If so, then we only ever perceive the parts of a temporally extended dynamic target and representing the whole is a distinct cognitive achievement. Once again, the atomist gestures at some post-perceptual cognitive operation as the source of seeming perception of motion. Notice that this auxiliary hypothesis hands off the burden of explanation to some independent model of memory and cognition, and atomism itself contributes very little besides stipulating the constraint that perceptual experience never represents relations between non-simultaneous events.⁷⁶

Furthermore, there are striking similarities between Zeno's proposed solution to the puzzle of motion and atomism. First, both deny that we perceive motion and change; Zeno because there is no motion to be the target of perception, and atomism because it holds that we cannot perceive temporal properties between non-simultaneous events. Second, both require an error theory to

⁷⁶ In Chapter 3, I reconstruct Le Poidevin's (2007) argument that temporal properties and relations are not proper objects of perception, which, if successful, would support the atomist thesis; I raise objections against the cogency of his arguments.

explain away the phenomenology of apparent motion perception. Third, atomism's zoetrope effect explanation reducing putative perceptions of motion into series of static experiences mirrors Zeno's decomposition of motion into successive motionless locations. Lastly, both cling to their anti-realist conclusions despite overwhelming phenomenological evidence to the contrary; Zeno denies the existence of motion and atomism denies the possibility of motion perception. So, despite the appearance of being able to accommodate the At-At theory of motion with auxiliary hypotheses about non-perceptual cognition, atomism's denial of motion perception is much more like Zeno's failed solution.

2.5. Conclusion

After surveying a number of arguments on both sides of the debate, and although I think I have provided persuasive reasons to prefer content extensionalism, I have not ruled out atomism as candidate model of temporal experience. Part of the challenge consists in the constant reminder that there is no disagreement about the phenomenology; both the atomist and the extensionalist agree that it seems as though, phenomenologically speaking, one perceives constant motion. From this exchange and much of my repeated criticisms of atomism, one might conclude that the disagreement hinges on the distinction between perception and cognition, despite many efforts to bracket this possibility. The atomist draws the scope of perception proper, narrowly, reducing it to direct sensory stimulation at a given time. By contrast, the extensionalist conceives of perception as a representational capacity for synthesizing sensory information sampled at multiple temporal scales and an active predictive process by which representations are continuously updated in a prediction-correction feedback loop. This is a significant disagreement about the nature of perception, and one that I tackle directly in Chapter 4, where I argue that content extensionalism

and its proprietary multi-scale sampling hypothesis provide a better functional explanation of how temporal perception works. In Chapter 3, I proceed to reconstruct and dissolve Le Poidevin's (2007) epistemological puzzle of time perception, and with it his argument denying that temporal properties and relations can be objects of perception.

3. DISSOLVING AN EPISTEMOLOGICAL PUZZLE OF TIME PERCEPTION⁷⁷

3.1. Preliminaries

Imagine a horn player blasting a brief trumpet riff, then muting the horn and repeating the riff. Listening to the performance, we hear two events: a clear loud riff followed by a softer muted riff. Surely, there are lots of features of the two events that we perceive. For instance, we hear the timbre and volume of each riff, the muffled intonation of the muted riff, and that the sounds are coming from the horn. We also seem to perceive how long each riff lasts and that the louder event precedes the softer event. There is some dispute, however, over whether or not we actually perceive the temporal features of events. Do we perceive an event's duration? Do we perceive the temporal order that holds between events?⁷⁸ If not, what are the bases of perceptual beliefs that we form about the duration and order of events? For those that respond negatively to these questions, their worry stems from the observation that temporal features of events are not causally efficacious and, thus, on a plausible causal theory of perception, cannot be perceived. Given this motivation for skepticism about temporal perception, it is instructive to examine the reasons for denying that the temporal properties of events play a causal role in the formation of perceptual beliefs, and to consider reasons for resisting such skepticism.

Perceptual belief, as I will understand it in what follows, is a belief non-inferentially formed on the basis of perception. Non-inferential formation implies that the perceiving subject does not consciously induce or deduce the content of the belief from perceptual data.⁷⁹ For example, I see and feel a dog in front of me, and I spontaneously form the belief that there is something warm

⁷⁷ This chapter is previously published, and appears here with permission, and can be accessed via the hyperlink: [Bowen, Adam J. 2013. "Dissolving an Epistemological Puzzle of Time Perception." *Synthese* 190 \(17\): 3797–3817.](#)

⁷⁸ Henceforth, whenever I use the term 'order' I will be referring to temporal order, i.e. the relation of temporal precedence and subsequence that events stand in to each other, not any other ordering relation (e.g., alphabetical order).

⁷⁹ BonJour (1985) calls this type of perceptual belief 'cognitively spontaneous'.

and hairy in front of me. By contrast, if I see canid paw prints in the snow and form the belief that a dog was there, then this belief is consciously inferred and not, strictly speaking, a perceptual belief. We entertain many consciously inferred beliefs from perceptual data, but such inferential beliefs about the temporal structure of events fall outside the purview of the present inquiry. Also, it should be noted that this definition of perceptual belief does not rule out beliefs resulting from unconscious inferential processes, nor does it rule out that unconscious computations play a role in generating perceptual beliefs. For now, however, I will put the details of empirical psychology to one side, and proceed by granting that we perceive events and somehow form perceptual beliefs about the order and duration of events. The principal concern at present is whether or not the temporal properties of an event play a causal role in the formation of such perceptual beliefs.

Le Poidevin (2007) claims that we do form perceptual beliefs regarding order and duration based on our perception of events, but neither order nor duration are by themselves objects of perception.⁸⁰ Simply put, he denies that we perceive the duration and order of events.⁸¹ Accordingly, there is no perception of an event's duration, only perception of the event which persists. Similarly, he claims that there is no perception of the order relation that obtains between events, only perception of the events in their respective order. Le Poidevin is making a subtle distinction between perceiving events in order, and perceiving the ordering relation itself. He admits that we perceive ordered events, but thinks that only after the fact can we represent the ordering relation that holds between them. Temporal properties are discernible only when one first perceives their bearers, and temporal relations are discernible only when one first perceives their

⁸⁰ "To see one event as following on from another, I have to be aware of the events themselves. The relation by itself cannot be an object of perception as pure colour can. Similarly with duration: I cannot be aware *just* of the duration of an event, independently of my awareness of the event itself. Somehow, the awareness of order and duration emerges from a perception of the events that exhibit them." (Le Poidevin 2007: 99)

⁸¹ Le Poidevin is not alone in this claim, cf. J.J. Gibson (1973), "Events are perceivable but time is not" (quoted by Pöppel 1978: 713)

relata. On such a view, the question remains as to whether or not our perceptual beliefs about order and duration are formed on the *causal* basis of an event's objective order and duration.⁸² Le Poidevin raises this issue in the form of an epistemological puzzle of time perception, from which he derives the claim that the order and duration of events do not causally contribute to our perceptual beliefs about them. Since his view is motivated by a causal truthmaker principle for grounding knowledge, it also holds that perceptual beliefs about temporal features must be caused by the features themselves in order to count as knowledge. Given these theoretical commitments, there is a puzzle concerning how such perceptual beliefs could constitute knowledge of temporal properties. I dissolve the puzzle by focusing on the case of audition and employing a distal event theory of sound to argue that temporal properties of sounds are among the targets of auditory perception, and that they are genuine, non-superfluous causes of auditory perceptual beliefs about the order and duration of sounds. In response to Le Poidevin, I argue for an account according to which order and duration are objects of perception, causally contribute to our perceptual beliefs about them, and such beliefs are capable of counting as knowledge. I conclude by showing that, on my alternative account, the epistemological puzzle dissolves and his own solution to it fails. Before proceeding to the puzzle, we should first clarify what conditions something must satisfy to be an object of a perceptual state for Le Poidevin, and whether temporal properties are candidates for being such objects of perception.

⁸² The term 'objective', in this context, denotes independence from a particular perspective. As such, the objective duration of, say, a sound is the temporal boundary of that sound, whether or not someone hears the sound lasting that long. If one grants the reality of events, then it is natural to assume that events are occurrents that have an objective temporal extent.

3.2. Objects of Perception

If we cannot perceive order and duration *per se*, then they “are not in any straightforward sense objects of perceptual states” (Le Poidevin, 2007: 99). Le Poidevin emphasizes this point by drawing a disanalogy between the temporal features and spatial features of what is perceived; he claims that spatial features are objects of perceptual states in a *straightforward sense*, whereas temporal features are not. He argues that a straightforward story can be offered as to how a spatial property, like the shape of a baseball, is itself an object of perception when the baseball is perceived.⁸³ The spatial properties of the baseball modify the distribution and properties of light rays which, in turn, modifies the visual perception of the baseball. Also, when I grip the baseball, its shape modifies the distribution of pressure affecting tactile and kinesthetic input. Le Poidevin can give a similar story about how the shape of the baseball modifies my perception of the transfer of energy and angular velocity when I spin the ball lightly in my hand or throw it forcefully, which is a variety of bodily perception. In each of these cases, Le Poidevin is observing that I am immediately aware of the shape throughout my experience of the baseball due to spatial properties modifying sensory input. So far, so good, there is a fairly straightforward story to tell about how spatial properties of an object are objects of perception when one perceives the object, given that they modify perceptual input. Le Poidevin has given us a criterion: x is an object of a perception just in case x modifies perceptual input in a way that makes the effects of x available to immediate awareness.⁸⁴

⁸³ Le Poidevin uses the example of an apple’s shape, but a baseball is a better example for raising the issue of bodily momentum perception.

⁸⁴ I am using ‘immediate awareness’ to denote the way in which Le Poidevin is purposely limiting the scope of direct perception, “perception has temporal limits, and if we draw these very tightly, certain things cannot be objects of (at least direct) perception.” (2007: 98). This is also why I have stipulated that perceptual belief, for our purposes, only concerns spontaneous non-inferential beliefs, i.e. those that concern direct perception and immediate awareness.

Le Poidevin argues that, by contrast, the temporal features of order and duration do not modify sensory input when perceiving an event in the right sort of way, because we are only aware of temporal information after the event is no longer being perceived, not immediately nor throughout the experience. If so, temporal features are not proper objects of perception. The crucial premise of this argument is the claim that temporal properties of an event are not available to immediate awareness. But, if order and duration do modify our immediate perceptual awareness of events, thereby satisfying Le Poidevin's criterion for being an object of perceptual states, then the crucial premise is false. To demonstrate, let us take, for example, the auditory perception of sounds: the amplitude of an audio signal changes over time and parameters of the resulting sound are sensitive to duration, which modifies the sonic character of the auditory perception by altering the oscillations of sound waves. The fine temporal structure of audio signals is typically modeled by four distinct durational parameters which constitute the ADSHR sound envelope: attack, decay, sustain/ hold, and release times [Fig. 4].⁸⁵

⁸⁵ For detailed treatment of the ADSHR temporal envelope theory, see Gordon (1987), Bregman (1990), Jensen (1999), Jensen & Marentakis (2001)

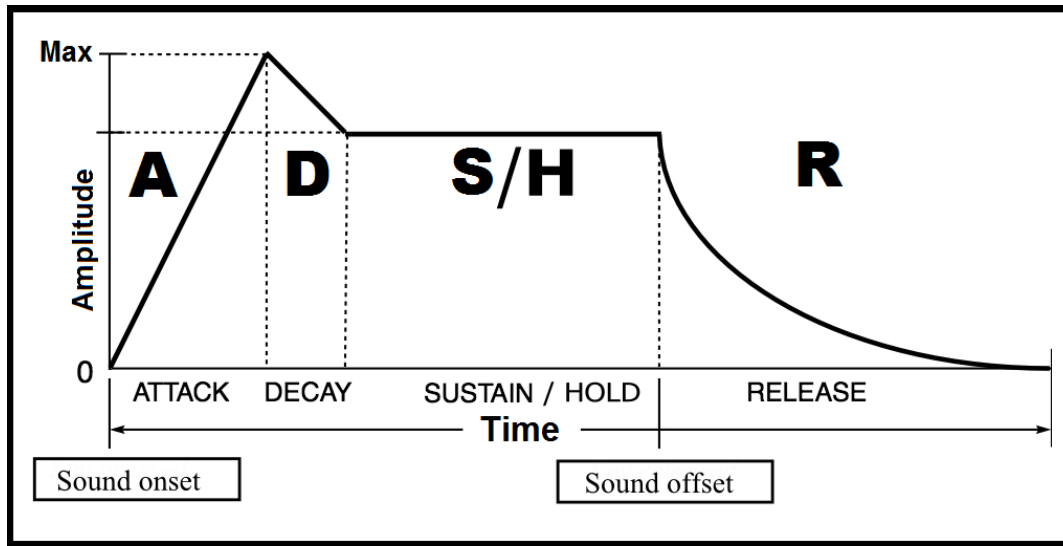


Figure 4. *Attack* is the amount of time a sound takes to reach its maximum amplitude, reaching the peak of the sound wave. *Decay* is the amount of time a sound takes to drop off to its sustain amplitude after the initial peak. *Sustain* is the constant amplitude a sound reaches after decay and *hold* is the amount of time a sound lasts at the sustain amplitude. *Release* is the amount of time a sound takes to fade after it ends.

Our understanding of the durational structure of audio signals has many significant applications which uniformly indicate that modifying the durational parameters of an audio signal causes perceptible changes in human audition, immediately and throughout one's awareness of the sound. In the production of music, compression amplification is a process used to control the dynamic range of a sound source like a musical instrument, and to even out volume fluctuations of recorded audio signals by reducing sound waves exceeding a volume threshold by a specified compression ratio. For example, a 1:6 compression ratio would decrease a sound's volume above a given decibel level by 1/6th its original output level. A compressor does not uniformly apply the same compression effect over the entirety of the sound wave, because doing so would compress the sound envelope without preserving the fine temporal structure of the sound. This would completely deaden the sound by flattening the envelope. Instead, the compression ratio increases incrementally from 1:1 to the specified maximum, 1:6, over a duration, i.e. the attack time of the sound, and the ratio gradually decreases until it returns to 1:1, i.e. the release time of the sound.

When programming the compression of an audio signal, sound engineers can adjust durational parameters of the ADSHR envelope to manipulate and transform sounds with precision. Such sound engineering interventions indicate that manipulating durational parameters modifies the perceptible quality of the sound. More importantly, for present purposes, adjusting temporal parameters of the sound envelope affects one's awareness immediately and throughout listening to the audio signal, not just after the sound event is no longer being perceived, which is Le Poidevin's claim about temporal properties.

To further illustrate, another important application of compression amplification is designing effective hearing aids (Hickson 1994: 52-65), which improve sound quality for listeners with sensorineural hearing loss. Compression processing in hearing aids is especially effective in controlling the dynamic range of speech sounds to make them more intelligible against background noise (Neuman et al. 1998: 2273-2281). In order for compression processing to be effective in hearing aids, the sound modifying adjustments to temporal parameters must continuously affect the perception of sound, otherwise the hearing impaired could not discern the signal from noise. If interventions like attack and release time adjustments change the audio signal and, in turn, cause listeners to hear the sound differently (or hear it at all), then temporal properties of sounds modify our perceptual input immediately and throughout the perception of the signal. If so, then temporal properties are objects of perceptual states on Le Poidevin's criterion. So, like the spatial properties of the baseball, the temporal parameters of the sound envelope are objects of perceptual states. Furthermore, temporal properties play an ineliminable role in our perception of sounds and, I'll quickly make the case that sounds are causally potent events.

Sounds are surely candidates for events that are perceived; in fact, the most comprehensive philosophical account of sounds (O'Callaghan, 2007, 2009) defends the view that sounds are events which stand in causal relations to auditory experiences.⁸⁶

Sounds have durations and are capable of surviving changes to their properties and qualities across time. Sounds stand in causal relations to the activities of objects and events that are sound sources, and *they fulfill the causal requirement on any account of their veridical perception*. Sounds thus occupy distinctive causal roles. (O'Callaghan, 2009: 16, my emphasis)

On this theory of sounds as distal events, sounds are caused by ordinary activities like strumming strings, crashing symbols, and buzzing lips while forcing air through horns; the sounds, in turn, cause reverberations and oscillations of waves through space which communicate the temporal parameters of the audio signal to the perceptual system or suitable recording device. It follows that sound events are causally potent. Additionally, sounds have durations, and an ordering relation which obtains between parts of sound events. So, if sounds are events, and the order of soundings and the durational parameters of a sound modify the sonic quality of an auditory perception, then the order and duration of a sound are objects of perception when the sound is perceived, in the same 'straightforward sense' in which the shape of a baseball is an object of perception when the baseball is perceived. If so, Le Poidevin's purported disanalogy fails, because order and duration are objects of perceptual states. This preliminary result will have consequences for my arguments against Le Poidevin's solution to the puzzle he raises for time perception. Let us now turn to the puzzle.

⁸⁶ This view directly opposes accounts that treat sounds as properties or secondary qualities, e.g. Locke (1690/1975, 1823) and Pasnau (1999). It should also be noted that my endorsement of O'Callaghan's account is neutral with respect to the ontological status of events; it is, in principle, compatible with any of the candidate views about events, e.g., Davidson (1970), Kim (1973), Galton (1984), Lewis (1986), and Bennett (1988).

3.3. The Epistemological Puzzle

Despite our disagreement about the status of order and duration as objects of perception, Le Poidevin agrees that humans are aware of temporal properties of perceived events without having to consciously infer or derive them from other perceptual information. Nonetheless, he holds that this awareness of temporal features is not perceptual, but *ex post facto*. With respect to duration he claims:

We are only aware of how long an event lasted when it has receded into our phenomenal past—when, in other words, the event has ceased to be an object of perception. (2007: 98)

The claim is that we are aware of duration non-inferentially, but awareness of an event's duration is only enjoyed after the event is no longer being perceived. The same goes for order; we can be aware that parts of an event occurred in a certain order, or aware that a series of events occurred in a certain order, but awareness of the ordering relation is only had "when it has receded into our phenomenal past." For Le Poidevin, this type of awareness is short-term memory or retentional awareness related to one's recent perception of an event, but not consciously inferred from one's perceiving the event. It is not immediate perceptual awareness, however, because order and duration are not proper objects of perception on his account. I grant that we do have this retentional awareness of order and duration, especially in cases of events and series of events which extend beyond one's present perceptual episode or exceed one's real-time representational capacity. Nevertheless, the above result, that order and duration are objects of perception in some non-trivial cases (viz. auditory perception), implies that we also have non-inferential *perceptual* awareness of order and duration in some cases.

Regardless of whether awareness of order and duration is perceptual or only retentional, the claim that we are non-inferentially aware of order and duration does not directly imply that such awareness is truth-apt or knowledge conducive. Rather, it is merely a phenomenological datum that we do in fact have non-inferential awareness of the temporal properties of events we perceive. Arguably, it might be the case that we only form beliefs about order and duration that count as knowledge on the basis of inference from standard reliable clock systems, but these would not count as *perceptual* beliefs. If, however, we do non-inferentially form perceptual beliefs about order and duration that count as knowledge, then there is some reliable process by which we acquire such beliefs. For now, we can bracket the issue of determining the details of what cognitive process is responsible for perceptual beliefs about temporal properties and relations.⁸⁷ We will instead focus on the epistemic problem of how our perceptual beliefs about the temporal order and duration of events can count as knowledge; a problem that arises once we grant both that we form perceptual beliefs about the order and duration, and that these beliefs are capable of counting as knowledge. The problem takes the form of an *epistemological puzzle of time perception*, which is an inconsistency resulting from the conjunction of the following four plausible claims:⁸⁸

(E0) There are perceptual beliefs about order and duration that count as knowledge.⁸⁹

(E1) In order for the perceptual belief *p* to count as knowledge, the truthmaker of *p* must cause the formation of the belief that *p*.

(E2) Objective order and duration are not the causes of our perceptual beliefs about order and duration.

(E3) Objective order and duration, or facts concerning them, are the truthmakers of perceptual beliefs about order and duration.

⁸⁷ Le Poidevin calls this the ‘psychological puzzle of time perception’, which is a separate problem but related to the epistemological puzzle of time perception.

⁸⁸ Le Poidevin, "The Wider View: Precedence and Duration" in his *The Images of Time* (Oxford: 2007), pp. 97-122

⁸⁹ I label the first claim 'E0' because Le Poidevin does not include it in his presentation of the puzzle, but it is required in order to explicitly generate the inconsistency.

Le Poidevin thinks the conjunction of (E1-E3) has the consequence that, “even if there is such a thing as temporal awareness, it cannot count as knowledge, since the truth-makers of our beliefs in these cases play *no role* in the causal history of those beliefs” (2007: 100, my emphasis). He then offers a solution to the puzzle which retains (E2) and (E3), but weakens the causal knowledge principle characterized by (E1). In §3.4, I will briefly explain the Causal Truth-Maker Principle equivalent to (E1) and grant its defensibility and plausibility, especially for those that share broadly held intuitions about reliable belief forming processes. I then focus my argument, in §3.5, on Le Poidevin’s defense of (E2) and offer several objections to the claim that objective order and duration cannot cause our perceptual beliefs about order and duration. I argue that objective order and duration do play some causal role in the formation of our perceptual beliefs about order and duration. After demonstrating that Le Poidevin’s lines of response are unconvincing and his defense of (E2) fails, the purported puzzle dissolves.

3.4. Causal Truth-Maker Principle

I will reformulate (E1) as the following equivalent principle:

Causal Truth-Maker Principle (CTMP): *A* knows that *p*, where the truthmaker of *p* is *t*, only if *t* plays a causal role in *A* coming to believe *p*.⁹⁰

Le Poidevin defends CTMP, which is an epistemological principle concerning the causal conditions for the acquisition of perceptual knowledge. Let us take a simple example to illustrate

⁹⁰ Le Poidevin’s formulation of CTMP is, “Perceptual beliefs that qualify for the title ‘knowledge’ are caused by their truthmakers” (100). The phrase ‘qualify for the title knowledge’ is equivalent to my ‘count as knowledge’ in (E1). My formulation of CTMP clarifies what Le Poidevin’s means by ‘Perceptual beliefs...are caused by their truthmakers’, viz. that a subject *A* knows the perceptual belief *p*, where *t* is the truthmaker of *p*, only if *t* causes *A* to believe *p*. I think making an instance of *p* the object rather than “perceptual beliefs” in the abstract makes the principle more concrete and more clearly shows the relation between *t* causing the perceptual belief that *p*, and knowing that *p*. I am grateful to Ben Goodney for pressing this clarification.

CTMP: Jed perceives a squirrel sitting under a tree and forms a belief that he is observing a squirrel sitting under the tree in front of him. Call his belief '*s*'. According to CTMP, in order for Jed to know *s*, the truthmaker of *s* must cause Jed to form the belief *s*. A clear candidate for the truthmaker of *s* is the state of affairs involving that particular squirrel sitting under that particular tree in front of Jed: call the truthmaker '*t*'. Jed's perception of *t* is not sufficient for *s* to count as knowledge, but something like truthmaker's causal sufficiency for *s* seems like a plausible necessary condition for the perceptual belief to count as knowledge.

CTMP is part of Le Poidevin's broadly reliabilist analysis of perceptual knowledge, which he calls a 'circumstantial dispositionalist account.'⁹¹ On his account, Jed knows that the squirrel is sitting under the tree just in case (a) it is true that the squirrel is sitting under the tree, (b) Jed's belief *s* is caused by the obtaining state of affairs, *t* (c) Jed is disposed to form the belief *s* when perceiving *t*, and *s* is true, (d) Jed's belief *s* was a manifestation of that disposition, and (e) the circumstances are such that, had *s* not been true, that disposition would not have been manifested. Le Poidevin offers this analysis of knowledge in response to typical Gettier-style counter-examples to the sufficiency of CTMP in conferring knowledge on perceptual beliefs. He argues that the counterfactual dependence required by condition (e) does not hold for certain Gettier-style cases. For example, if Jed perceived a cleverly designed squirrel robot and formed the belief *s*, then it would not be a manifestation of the truth-apt disposition and would not count as knowledge. We will not pursue the details of these broader issues or rehearse the typical objections, because Le Poidevin is only claiming that CTMP is a defensible and plausible necessary condition for the acquisition of perceptual knowledge. The plausibility of CTMP stems from externalist intuitions that the justification for one's beliefs is grounded in reliable causal connections between oneself

⁹¹ See Le Poidevin (2007: 29), cf. Nozick (1981) for the dispositional component of this form of process reliabilism.

and the world.⁹² Also, CTMP is an epistemological extension of truthmaker theories which are generally motivated by broadly held intuitions that truth should be grounded in, or supervene upon, what exists.⁹³ Thus, CTMP is plausible for anyone who shares general truthmaker intuitions, or who wants an account of how the justification of our perceptual beliefs is causally grounded in the external environment. So, we can provisionally accept (E1), for the purpose of critiquing Le Poidevin's solution to the epistemological puzzle of time perception, of which CTMP is the second of four jointly inconsistent propositions.

3.5. The Acausality of Temporal Order and Duration

Le Poidevin defends (E2), the acausality of order and duration, which is the claim that perceptual beliefs concerning order and duration are not caused by objective order and duration. He begins the defense by drawing on the location problem for relational properties.⁹⁴ That is, relational properties do not seem to have spatio-temporal locations. Consider the proposition *that Chicago is north of Champaign*. Where and when is the *north-of* relation located? On Russell's (1912) analysis, the correct answer is "nowhere and nowhen"; these types of relations are universals, hence not the sorts of things which are located. Le Poidevin takes this to imply that if Russell is correct, then relational properties are not causes, because causes must have spatio-temporal locations in order to produce effects at the times and places that they do. So, there is a strong conceptual motivation for claiming that order and duration are acausal. Assuming that temporal properties are universals which lack locations, and causal efficacy requires spatio-temporal locations, it is a small step to the conclusion that order and duration are acausal.

⁹² See Goldman (1979, 1986) and Dretske (1981, 1995) for defenses of externalist accounts of justification.

⁹³ For defense of truthmaker see Armstrong (1997), Cameron (2005, 2008_{a, b}), Schaffer (2008, 2010), for an extended argument against truthmaker see Merricks (2007).

⁹⁴ See Le Poidevin (2007: 101-102), cf. Russell (1912: 56)

What if you are willing to abandon the Russellian account of universals? Le Poidevin also considers treating relations and properties as tropes,⁹⁵ i.e. particularized tokens of a type, and he thinks that this strategy fares no better with the location problem. He reasons that the trope theorist has the same problem of assigning relational properties to a location. Where is the *north-of* trope located in our example? He claims that it would be ad hoc to locate this token of the relation in either Chicago or Champaign. Locating it in both places would seem to belie the trope's status as a particular, because particulars cannot be located in two places at the same time. So, he concludes:

Even if we are dealing with the trope rather than the universal, perhaps the best thing to say is that the relation is *nowhere*: it does not have a spatial location at all. (2007: 102)

Le Poidevin's dismissal of a trope-theoretic answer to the location problem is a bit perfunctory. The trope theorist might claim that the *north-of* relation is located all over the place—*north-of-x* tropes are located at all of the spacetime points between *x* and anything else north of *x*. By this, I do not mean to suggest that the same particularized property is all over the place, rather I am suggesting that on some interpretations tropes can be distributed particulars.⁹⁶ The actual account would be much more complicated, but we should recognize that there are live options available to varieties of trope theory which could locate spatial relations by grounding them in concrete particularized instances (tropes) of relational properties. Le Poidevin is evaluating the prospects of a trope-theoretic answer on the basis of a limited sample. Of course, if you are committed to the idea that there are no distributed particulars, for independent reasons, then you should side with

⁹⁵ For treatments of trope theory, see Armstrong (1989), Bacon (1995), Mormann (1995), and Simons (1994)

⁹⁶ For example, we might claim that the brownness trope of a piece of chocolate is distributed throughout the chocolate. We could alternatively claim that there are thousands of brownness tropes in the chocolate, one for each micro-particle of the chocolate. But, I am not endorsing one interpretation over the other, because I think both are adequate candidates for answering the location problem. I am grateful to David Ingram for pressing me to clarify this point.

Le Poidevin and agree that it is correct to dismiss the trope view because it cannot help to solve the location problem.

My point, however, is that just because some obvious options for analyzing properties do not provide a worked-out theory of how a relation could be spatio-temporally located, does not imply that such a theory is untenable. It is certainly possible that the best account for locating such properties is yet to be postulated—for the sake of job security and future philosophers, we ought to hope that some problems are still unsolved. Perhaps, the best thing to say, *pace* Le Poidevin, is that it *is* possible to locate relations, but such a theory might commit us to a nominalist ontology of relations and properties. Nominalism is not such a bad position anyhow, especially if one entertains independent reasons for thinking that universals are ontological extravagances. On this score, a nominalist ontology only quantifies over particulars, whereas the alternative quantifies over both particulars and universals, so it certainly has the advantage of parsimony. Also, if one wants to defend some form of nominalism to avoid having to accept the existence of universals, then trope theory is the most promising option because it doesn't face the difficulties which beset other resemblance-class nominalisms.⁹⁷

Notwithstanding the possibility of locating relations and relational properties, Le Poidevin argues from the premise that relational properties lack locations to his conclusion that order and duration are acausal. We can schematize his Argument from the Location Problem as follows:

- (L1) If x is a cause, then x must be spatio-temporally located.
- (L2) Relations and relational properties lack locations.
- (L3) So, relations and relational properties are not causes
- (L4) Order and duration are relational properties.
- (L5) If so, then order and duration are not causes.

⁹⁷ Namely, the problems of *companionship* and *imperfect community*, cf. Goodman's *Structure of Appearance* (1951).

(L6) Thus, objective order and duration are acausal.

So, the argument directly supports E2 from the epistemological puzzle, since L6 is a restatement of it. If we can demonstrate that relations and relational properties are causes, then either L1 is false or L2 is false, and Le Poidevin's argument is unsound. Take for instance an object that floats in water. What causes the object to float in water? Flat-footed answer: the object's being less dense than the water. The relational property of *being less dense than* seems to be a cause of the object's floating. Le Poidevin might reply that it is the object's density, an intrinsic property of the object, which is the cause of its floating, not some relational property it has with respect to the water. This reply misses the mark, because the object's density would not cause it to float, if it were placed in a liquid which was less dense than the object. Rather, the object would sink as predicted by Archimedes' buoyancy principle. So, an object's floating or sinking in a liquid is counterfactually dependent upon the relational property that the object bears with respect to the given liquid. At the very least, this example should cast doubt on Le Poidevin's claim that being a relational property entails that the property is acausal; especially considering that Le Poidevin is primarily concerned with the indirect causation of perceptual beliefs. That is, CTMP only requires that the truthmaker of p play a causal role in the formation of the belief that p .

As a result, we should not accept so easily the conclusion that order and duration are acausal. Recall that Le Poidevin began with the observation that the order and duration are not the sorts of things that can be perceived; we only become aware of them after we perceive the event or events that exhibit them. He rightly concedes that just because (on his view) order and duration fail to be objects of perceptual states, "it does not immediately follow that they are not causes of those states" (2007: 101), because being causal is not a sufficient condition for being an object of perception. Nevertheless, he finds it implausible and puzzling how features of the world that we never perceive

can causally contribute to our perceptual beliefs. For this reason, he uses the Argument from the Location Problem to provide reasons for thinking that order and duration, as relational properties, cannot by themselves be causes of our perceptual beliefs. I have outlined two preliminary ways to resist this move: (i) by working out a theory for locating relational properties or (ii) to develop examples of causally efficacious relational properties, thereby showing that either causes need not be located or that relational properties are located. In the remainder of this section, I want to sketch how the duration of an event could cause my representation of that duration. In §3.6, I return to the theory of sounds as distal events to provide a more detailed objection to the location problem, by locating duration in the physical structure of sound events, and showing how the durations of sounds play a causal role in forming perceptual beliefs about them.

To illustrate the possibility of an event's duration causing a perceptual state, take the generalized case where I perceive an event e persisting over some interval Δt . While e is the object of my perception, a property of e is the amount of time it persists, Δt . In a veridical case, my perception of e which lasts for Γt is caused by e 's property of persisting Δt , if there is a reliable mechanism by which Γt represents Δt . Only in virtue of e having some objective duration Δt , which is represented in my perception of e as Γt , can I come to form the belief that e lasted Δt . This does not rule out my getting it wrong; my belief would be false if I over- or underestimated the length of e 's interval, and in such cases my belief thereby would not count as knowledge.⁹⁸ In cases where I do get it right, however, my belief is made true by the fact that an event's perceived duration matches its objective duration. If an event's duration is a property of the event, and perception of

⁹⁸ In fact, humans are notoriously bad at estimating extremely brief durations (on the order of 1-400 msec.) and longer durations (on the order of minutes and hours) without external reliable clock systems and memory, but medium-length estimations (on the order of seconds) can be accurately reported without aid. Varela (1999: 277) claims that, "subjects can estimate durations of 2-3 seconds quite precisely, but their performance decreases considerably for longer times; spontaneous speech in many languages is organized such that utterances last 2-3 seconds; short intentional movements (such as self-initiated arm movements) are embedded within windows of the same duration." See also Varela (1995) for a more extensive treatment of the psychological and cognitive-neuroscience support.

that event causes the belief that the event has the duration that it does, then the duration of the event plays a causal role in my forming the belief. This is true even when we grant that my awareness of the duration is delayed and subsequent to the event, given the empirical evidence of stimulus reaction delays in cognitive systems.⁹⁹ Just because my perception of the duration is not simultaneous with the stimulus event does not imply that duration is not a property of the event that causes my perceptual belief. Le Poidevin is denying that objective duration can be causal in any respect, on the grounds that duration is not located, but we will see that this is also mistaken.

3.6. Locating duration

Le Poidevin claims that duration is a property that lacks location, and if it is not located, then it is acausal. Consider my perceptual belief that a trumpet blast lasts 3s. My belief about the duration of the trumpet sound cannot be caused by a bare perception of duration, since we agree to the obvious claim that properties of an event are not perceived in the absence of the event.¹⁰⁰ Nevertheless, I argued in §3.2 that the duration of an event is an object of perception when the event is an object of perception, which does not require a bare perception of duration itself. This section challenges the soundness of Le Poidevin's inference by defending a theory of sounds as distal events (introduced in §3.2) which both provides a plausible solution to the location problem and has significant advantages over the rival theory that identifies a sound with its waves.

Allow me to apply the theory of sounds as distal events to the example of the trumpet blast. The activity of the trumpet player buzzing her lips on the mouthpiece and forcing air through the trumpet causes the trumpet sound. The sound event causes sound waves to oscillate through

⁹⁹ Libet *et al.* (1967, 1991), and Jensen (1979) offer studies that purport to show that reaction times to skin stimuli is around 500 msec. A delay does not entail that duration is not a causal part of the perception.

¹⁰⁰ Unless we are in Wonderland, where one can see properties without their bearers, e.g., "a grin without a cat."

spacetime reaching the cochlea in my inner ear which detects pressure impulses from the waves and, in turn, produces electrical impulses along the auditory nerve which encode the temporal parameters of the audio signal. The trumpet sound's objective duration of 3s directly modifies the oscillations of the sound waves, which communicate the sound to my auditory senses. Part of what is communicated by the sound waves is the temporal extent of the sound event. Notice, however, that on this view a sound is not identified with the waves it causes. The waves represent information about the sound event to the perceiver, but the waves are not identical to the sound. The trumpet sound is located near its source, the trumpet, which is precisely where we hear it to be located. I don't hear the trumpet sound to be in my ear, I hear it located where the trumpeting takes place. O'Callaghan clearly states this feature of the theory:

Sounds, I claim, are located roughly where we hear them to be: at or near their sources. The sound does not travel as do the waves. The waves, however, are causally intermediate between the sounds and the auditory experiences of perceivers. The waves bear or transmit information about sounds through the medium, and thus furnish the materials for auditory experience. Sounds are stationary relative to their sources. If sounds are stationary events, then the auditory experience of location does not involve a systematic and pervasive illusion, and audition-based beliefs about the durations of sounds are for the most part true. (2009: 14-15)

Why does identifying sounds with their waves imply that the auditory experience of location involves a 'systematic and pervasive illusion'? One reason is that auditory experiences represent, to a greater or lesser degree, the location of a sound source within one's environment, which is known as 'extracranial localization' (Gelfand 1998: 374). If a sound were identified with its wave, which oscillates dynamically through space instead of being located near its source, then

perceptual beliefs regarding the locations of sounds would be systemically erroneous.¹⁰¹ Alternatively, an auditory system with a reliable extracranial localization function has clear adaptive advantages because we can, say, identify where the rattlesnake's rattle is coming from and avoid a potentially fatal bite. Of course, an adaptive advantage does not imply that it is a truth-tracking advantage. Fair enough, but the view on which sounds are located at or near their sources provides a plausible story for why our auditory system is able to reliably detect the direction from which an audio signal originates (viz., where the sound is located) and estimate the distance. The alternative is in a worse explanatory position; if sounds were anywhere and everywhere the signal carries them, then reliable extracranial localization of sounds would be a mystery in need of further explanation.

A second problem, indicated in the O'Callaghan quote, is that the pervasive illusion implied by the wave theory also infects all our duration-based beliefs. According to the wave theory, sounds are moving objects, identified with sound signals, and source location is only part of the story about sounds, viz. the beginning of the story. The sound itself travels as a wave and thereby arrives in the inner ear, so the sound is both at the source and at the receiver of the signal, and many diffuse places elsewhere. It follows that if one identifies sounds with the sound waves themselves, then sounds are weird growing and diffusing oscillations through space. The problem is that the signal becomes weaker and noisier as it travels from the source and stretches in spacetime. If sounds are identical to the expanding sound waves, then a sound which we record near the source to last, say, 10s is actually of a much longer duration since the waves expands further throughout spacetime, spreading and diffusing. Thus, our belief that the sound persists for 10s is false. Let us call this the 'Diffusion Problem': if you hold that sounds are identical to sound

¹⁰¹ See O'Callaghan (2010) for an extended defense of the sound localization against skeptical challenges.

waves then, (a) a sound duration is vague or indeterminate due to diffusion of signal, (b) sounds are indefinitely expanding objects or events that undergo continuous change, and (c) beliefs about precise durations of sounds are false. To put the problem in a practical way, the wave theory is in tension with the applied science of sound recording, which operates on the assumption that a diffuse signal is not identical to the sound from which it originates. For this reason, sounds ought to be, and usually are, recorded as close as possible to their sources; for example, microphones and pick-ups are positioned relatively close to the instruments, the sounds of which the recording devices are designed to receive and transmit. The metaphysical ramifications of the wave theory is at odds with this practice. Does the sound as stationary event theory also face a version of the Diffusion Problem?

On the view I endorse, sounds produce signals which transmit information about the event's duration to my auditory system, which integrates the information into a percept. On the basis of this integration, I come to form perceptual beliefs about the sound event, like how long it lasts. Stationary sound events still have a wavelike oscillatory shape, because the physical form of the sound is produced by the vibrations of the source and is represented in the signal it creates. Although there is a distinction between the sound event and the signal it creates, the signal is an isomorphism of the sound, especially near its source. This explains the placement of recording devices in close proximity to sound sources, in order to record the structure of the sound—including its temporal parameters—before the signal propagates.

If one distinguishes a sound from its signal, which is only a representation of the sound, then one can measure exact sound durations at the source and avoid the Diffusion Problem by acknowledging that the signal becomes a weaker representation of the initiating sound as it expands. Instead of an isomorphism, the signal becomes an increasingly weaker quasi-

homomorphism of the sound as it diffuses through spacetime. So, in addition to preserving localizations of sounds, another virtue of the distinction between sound and signal is that it preserves the integrity of sound durations and expediently avoids the Diffusion Problem.

Returning to the challenge of locating duration, if sound events have durations and are located at their sources, then the duration of a sound event is distributed throughout the sound event.¹⁰² Sounds produce signals which transmit information about the event's duration to my auditory system and I come to form perceptual beliefs about the sound event. The sound event's instantiating the property of lasting for 3s is a candidate truthmaker for my perceptual belief that a trumpet blast lasts 3s.¹⁰³ So, on the present theory of sounds as events, we can answer Le Poidevin's location challenge and provide a story on which the duration of an event figures centrally in the causal history of perceptual beliefs about duration, at least in the case of audition.

Le Poidevin anticipates this sort of answer to the location challenge, and offers the following rebuttal:

It does not help to point out that duration and precedence are consequences of events' temporal locations, for this relies on those locations themselves being temporally extended and standing in temporal relations to each other. (2007: 102)

He is suggesting that an appeal to the interval of an event to locate a property of duration is unhelpful because the locations must themselves be temporally extended, i.e. doing so presupposes what is being analyzed. My proposal is slightly different, because in addition to temporally

¹⁰² Mapping the sound event in 4-space, the duration would be located along the temporal dimension.

¹⁰³ Our perceptual beliefs about duration, probably, only rarely give numerical values. We can, however, ostensibly specify the duration by comparing it to a duration of equal magnitude. In fact, humans are quite good at this within the range of 500ms - 3s, *temporal reproduction* tasks in experimental psychology test for precisely this ability to reproduce durations. For good examples of this experimental method and results, see Wittmann *et al.* (2007) and Ulbrich *et al.* (2007).

locating sounds, the distal event theory of sounds provides a systematic ontology for locating sounds in space as well. When and where is trumpet blast located? Over the 3s interval of the sound event, and at or near the source of the sound. Recall that a sound is shaped like a wave, because it is isomorphic to and carries the information caused by the reverberations of its source. So, if we were able to measure the initial three second interval stretching from the trumpet's bell, at the exact time of the blast, then we would be able to exactly locate the sound event in spacetime. In fact, modern recording equipment does an adequate job recording and representing the structure of the sound event, including the fine durational parameters of the sound envelope.¹⁰⁴ If we also know the exact location of the sound source in space, then we have the resources to provide accurate specifications for locating a particular sound. When I claim that duration is distributed over the entire interval, this does not commit me to the view that the total duration exists at each moment of the sound event. Rather, the total duration only exists over the entire interval of the sound event.¹⁰⁵ A particular duration is a distributed property in spacetime, which explains my sympathy for finding an account that locates relational properties in the world.

Le Poidevin claims that this response puts us in a position of needing to answer why, if the duration is extended throughout the event, is it incapable of causing the same effect at all parts of the event? The property of having 3s duration is exemplified over the 3s interval of an event, not at each second of that event. For instance, at 1s into the perception of a sound event, I form the belief that the sound has lasted one second so far; we can claim that the duration of the event up to that first second caused the corresponding perceptual belief. If the sound continues for another

¹⁰⁴ Note, that on the view I am advocating, when you amplify and replay an audio recording you are creating a new sound event that bears some ancestral relation to the original sound that was recorded. This has the interesting implication that the most replayed recordings have the most ancestors.

¹⁰⁵ It is like asking the question 'when and where does the Earth revolve around the sun?' The correct answer is that one revolution of the Earth around the sun occurs over an interval of ~365 days and over the path of its elliptical orbit. Each time-slice along the Earth's orbital path is a state that belongs to the revolution, but it is only the entire path traveled over a year which is identical to a revolution.

2s before ceasing, only then could the duration of the event cause the perceptual belief that *the sound lasts 3s*. On the analysis I am suggesting here, durations are the sorts of properties distributed throughout a particular event, so the duration is isochronous to the extent of that event. That is, duration is nothing over and above the temporal extent of an event.

I do not claim that we are always, or even most of the time, consciously aware of timing the duration of events and forming perceptual beliefs about durations.¹⁰⁶ Rather, sometimes we do form true beliefs about the duration of brief events on the basis of our perception of these events. In such cases, which should count as perceptual knowledge, it is correct to claim that the truthmaker of the belief, viz. the persisting event, causes the belief. Since the duration is inextricable from the extended event, the objective duration of the event plays a central role in the causal history of the belief.¹⁰⁷

3.7. Beyond the location problem

Even if we solve the location problem, Le Poidevin argues that there are further difficulties with granting that temporal order and duration can be causes. He contends that all cases of the purported causal efficacy of temporal properties can be explained away, including those unrelated to perception or perceptual knowledge. Take his case of some pasta's being cooked because it has been boiled for 10 min. The mere passage of ten minutes does not cause the cooking. Le Poidevin claims that it is the individual events that take place during the 10 min that cause the pasta to be

¹⁰⁶ I would claim instead that we normally outsource most of our timing to external reliable clock systems for three related reasons: 1) doing so frees up a lot of cognitive resources for other tasks; 2) our external temporal metrics are much more accurate over extended durations and extremely brief durations, thus grounding more true judgments about durations; and 3) there is likely an evolutionary advantage to cognitively outsourcing in this way (given 2 and 3). I think this claim would follow naturally from the Extended Mind thesis argued for by Clark & Chalmers (1998) and Clark (1997, 2003, 2008).

¹⁰⁷ Locating the order relations that obtain between two or more events may pose a more difficult task. Nonetheless, I think we can tell a plausible story, *ceteris paribus*, in which the objective orders of events cause corresponding perceptual beliefs about order.

cooked. I agree; no one would defend the ridiculous view that mere temporal passage causes the cooking of pasta, but I find it puzzling that Le Poidevin denies that the duration of the event has any causal contribution whatsoever. The individual events occur over an interval of 10 minutes and those same events could not have occurred over a briefer interval. If so, and if the events cause the cooking, then the durations of the events are, in part, constitutive of the cause.

Le Poidevin might reasonably object that the same events *could* take place over a briefer interval, if the rate of change were accelerated, which supports his view that the individual events taking place are causal, not the interval over which they take place. At the original rate of change, the pasta requires 10 min of boiling to be fully cooked, whereas if the rate of change were increased two-fold, then the pasta would only require 5 min of boiling. Pushing back, I submit that the rate of change is another temporal relation of the events, since it represents the number of changes per unit of time. Thus, by modifying the causal story to focus on rate of change, we cannot eliminate the role played by duration, since the individual events' rate of change over a particular interval is what causes the pasta's being cooked. If the events cause the cooking, then the rate of change of the events *and their duration* are, in part, constitutive of the cause.¹⁰⁸

A more sophisticated example from nuclear science, suitably simplified for ease of exposition, will lend support to my claim that the specific orders and durations of causally efficacious events are not eliminable from causal explanations of those events. Nuclear chain reactions occur when the neutrons emitted by a fission event cause additional self-propagating fission events instead of either (a) being absorbed by non-fission capture events or (b) escaping the system.¹⁰⁹ These reactions are sensitive to durational properties of fission events, including both the average time between neutron emission and absorption or escape, known as 'prompt neutron lifetime', and the

¹⁰⁸ Thanks to an anonymous referee for suggesting the possible appeal to rate of change.

¹⁰⁹ See Lamarsh, John & Baratta, Anthony (2001). *Introduction to Nuclear Engineering* for details and equations.

average time from neutron emission to absorption into a capture event that results in fission, known as 'mean generation time'. In order to maximize the explosive power of fissile material, nuclear weapon design requires engineering a prompt supercritical assembly in which the number of fission events increases exponentially over a brief duration causing the release of explosively large amounts of energy on the order of hundreds of millions of electronvolts. Accordingly, nuclear engineers use the durational parameters of fission events to calculate the amount and type of fuel required to generate a rapid and intense enough reaction to produce such an explosion. The causal explanation of a nuclear chain reaction directly relies on the prompt neutron lifetimes and the mean generation times of fission events, i.e. these physical durations play ineliminable causal roles in chain reaction events.

In response, Le Poidevin must claim that it is the fission events that cause the nuclear chain reaction, but the durational parameters of those events are strictly acausal. Again, I agree that no one would claim that the mere passage of time causes chain reactions, but it is empirically suspect to claim that such reactions are not causally sensitive to durational parameters, because (as we have seen) the properties of order and duration can partly constitute causally efficacious events. Perhaps, a charitable way to read Le Poidevin's skepticism about temporal properties being causal, in light of the nuclear chain reaction example, is to interpret him as claiming that temporal properties in scientific explanations are merely operational and not ontological. His rebuttal might go as follows: nuclear scientists and others use temporal variables to calculate the states of physical systems. For example, the purported durational property, prompt neutron lifetime, is merely a way of determining how much fissile material is needed to maximize the amount of neutrons absorbed into capture events resulting in exponentially increasing fissions. But, the duration is not doing any causal work at the level of *reality*.

The first part of the possible objection makes a lot of sense, since scientific models operationalize variables into quantifiable factors for the purpose of computation and prediction. And, given that fissile material is highly unstable, you need some way of calculating the conditions required for generating a nuclear chain reactions. Nevertheless, this response misses the force of the example, because the precipitating conditions of chain reaction fission events are causally sensitive to temporal parameters. Also, the very process that is engineered, the prompt supercritical assembly, is extremely time sensitive in its own right. Only if you ensure enough fissions per unit of time, will the supercritical assembly be *prompt* enough to produce an explosive chain reaction. So, the engineers are making calculations concerning the number of fission events based on probabilistic physical durations like the prompt neutron lifetime and the mean generation time to ensure the exponential increase in fission events within the *real* interval of a few milliseconds. Every stage of this causal explanation requires functional representations of temporal parameters; so, unless you are an anti-realist about time, you should find the example to be a compelling case of temporal properties playing non-superfluous causal roles.¹¹⁰

Le Poidevin's own solution to the epistemological puzzle is to maintain that order and duration are acausal and revise CTMP, weakening it to the following principle:

Explanatory Truth-Maker Principle (ETMP): Perceptual beliefs that qualify for the title 'knowledge' have truthmakers that figure in a full explanation of the acquisition of those beliefs. (2007: 116)

The ETMP is a weakened principle in comparison to the CTMP, because it no longer requires that truthmakers play a causal role in the acquisition of the beliefs which they make true. This form of weakening undermines some of the externalist intuitions that motivate causal theories of

¹¹⁰ Le Poidevin is certainly not an anti-realist, since his epistemological puzzle directly refers to 'objective order and duration'.

perceptual knowledge, since it replaces the requirement of a causal relation between belief and truthmaker with an ambiguous relation of 'figur[ing] in a full explanation'; in assessing the merits of this revised principle a lot will ride on how such figuring is specified. In an effort to do so, Le Poidevin proposes a new kind of explanation, of which objective order and duration can figure in the explanation of how we come to form beliefs about order and duration. He coins this type of explanation 'chronometric explanation', which includes reference to the temporal locations of events, the temporal extent of events, or to the rate of change. Le Poidevin stipulates that chronometric explanation is a distinctively non-causal form of explanation.¹¹¹ Nevertheless, this move seems to be an *ad hoc* strategy to solve his puzzle while maintaining the acausality of order and duration. I understand *ad hoc* moves to be those revisions to a theory that modify it in such a way to make it immune to a single problem, but fails to generate any new predictions or cover a broader range of phenomena. I recognize that his move to posit chronometric explanation was not intended as a scientific hypothesis, but it is offered as a way to get temporal properties back into a more complete explanation of how we come to have perceptual beliefs about order and duration. Le Poidevin concedes that his chronometric explanation and the ETMP play the same role as CTMP, with the only difference being that he can maintain the acausality of temporal properties and relations. This might be an important virtue, and conceptual grounds for following Le Poidevin, if your elect theory of causation struggles to accommodate cases where temporal properties appear to play causal roles. Thus, he is helping himself to all the causal explanations available to accounts like mine, while strategically screening off chronometric elements from playing causal roles. He certainly hasn't increased the explanatory power of the theory nor has he

¹¹¹ Cf. Nerlich's (1994: 41) for a discussion of geometrical explanation, which Le Poidevin cites as having affinities to his proposal, and is likely the source of his idea since geometrical explanation is also stipulated to be a non-causal explanation.

given independent reasons, beyond his Argument from the Location Problem, for thinking that temporal properties are unequivocally acausal. Furthermore, my examples from sound engineering and acoustical science offer significant countervailing reasons to think that temporal properties and relations are causally salient to both auditory perception and our ability to process signals in broader contexts (e.g., hearing aid technology and music production).

To be fair, let us examine whether the introduction of chronometric explanation provides any additional advantages. In the course of explicating chronometric explanation, he says:

Often it will occur in the context of a causal explanation. Thus, a certain effect may be explained, not simply by the existence of an antecedent cause, but by the location of that cause in time, or by the interval between that cause and another item, or by the rate at which some antecedent change proceeded. (2007:117)

Le Poidevin's stipulation that chronometric explanation is non-causal does not seem to get him very far, since it occurs in the context of causal explanations. All the heavy lifting of satisfying ETMP is done by integrating chronometric with causal explanations, and the distinction between the supposedly distinct forms of explanation is predicated solely on the claim that order and duration of events cannot play causal roles; a claim, and arguments given for it, which I have attacked on multiple fronts. Thus, chronometric explanation appears to be non-causal in name alone. Le Poidevin owes us an independent argument for why we should accept that this is a distinct form of explanation, other than an expedient solution to his puzzle. Chronometric explanation suspiciously serves the same purpose as my claim that temporal location of an event and durational parameters of an event are properties of the event itself, properties invoked to give causal explanations across a wide-range of phenomena from auditory perception to nuclear engineering. Le Poidevin's proposed solution seems to be motivated by his strong conceptual

commitments concerning the acausality of order and duration, resulting from both his puzzlement about how temporal properties could be proper objects of perceptual states and his causal worry about the location problem. Thus, he invokes chronometric explanation in conjunction with the ETMP in order to give an account of how we come to form perceptual beliefs about the order and duration of events, and to preserve his commitment to the acausality of temporal properties.

I have argued that we can give a much simpler analysis of the epistemic relation between the order and duration of events and our perceptual beliefs concerning them, once we recognize that order and duration are objects of perception and are poised to play causal roles in perceptual belief formation. If we deny E2, the acausality claim, then the epistemological puzzle of time perception dissolves. I have offered significant reasons for denying E2 and affirming that order and duration of events are causal in some non-trivial respects that accord with current scientific practice. Finally, Le Poidevin's solution to the puzzle ought to be rejected on the grounds that it weakens the truthmaker principle, invokes an artificial distinction, and rests on the spurious insistence that order and duration are always acausal.

4. MULTI-SCALE SAMPLING AND INTEGRATION AS A BASIS FOR TEMPORAL PERCEPTION

4.1. Introduction

Complex human behaviors display a wide range of temporally sensitive coordination, interaction, and perceptual discrimination. There are numerous practical and adaptive advantages gained by sensitivity to temporal features of a changing dynamic environment. The capacity to distinguish ballistic from non-ballistic motion, for instance, enables one to detect and avoid predators as well as to identify and track prey. Also, the capacity to recognize and produce speech patterns enables communication, which is imperative for the interaction of social animals. Paradigm examples of human culture also thrive on temporally mediated behaviors and indeed on capacities for fine temporal discrimination: creating and appreciating music, catching or hitting a baseball, or coordinating the movements of a dance routine. In addition, of course, in the present era of computer-based activities, mastering timing and sensorimotor coordination is necessary to successfully utilize technological devices as effective work tools as well as to enjoy their various gaming capacities.¹¹² Our success at engaging and interacting with dynamic environments whether in the world or the cyber-worlds of human-machine interfaces strongly suggests that humans possess cognitive capacities for perceiving temporal properties and relations, specifically order, duration, succession, and synchrony.

Supposing that humans do perceive temporal properties of, and relations between, external stimuli, the inquiry shifts to the question: what cognitive processes and mechanisms make this possible? Among cognitive psychologists and neuroscientists skepticism about temporal perception is unwarranted, and thriving research programs are dedicated to investigating

¹¹² In fact, many video games increase level of difficulty as a function of timing task performance; even the classic puzzle game *Tetris* increases difficulty simply by increasing the rate at which the puzzle pieces fall, thereby reducing the amount of time a player has to rotate and position each piece.

hypotheses regarding both the functional capacities and neural processes that realize those capacities for temporal perception.¹¹³ In this chapter, I likewise table the skeptical worries and proceed from the assumption that the temporal perception is a legitimate target of investigation, and consider competing models of how it works for creatures like us.¹¹⁴

Although some philosophers doubt that we ever perceive temporal properties at all, because temporal properties and relations are not objects of perception (Le Poidevin 2007), they often agree that we seem to have temporal experiences and offer alternative accounts of non-perceptual temporal representation.¹¹⁵ Along these lines, temporal atomism is the view that perceptual experiences can only represent what is happening at a given time, and thus we do not perceive temporally extended events instantiating temporal properties and relations (Chuard 2011: 8). According to atomism, putative temporal experiences, say, *as of* a baseball in motion or *as of* a melody unfolding, are a result of the successive combination of discrete perceptual experiences. I visually perceive the baseball at each spatially contiguous location along its trajectory at successive times, and each distinct perception represents only a single temporal part of the ball's motion. Why do I seem to see the ball moving, if I do not perceive temporal relations between non-simultaneous events?

¹¹³ Of course, the sociological fact that these projects are thriving (i.e. well-funded) does not entail the accuracy or legitimacy of a particular research program. Nevertheless, examining the empirical evidence and making an informed judgment about the explanations on offer is methodologically more satisfying than armchair skepticism. Also, the current research improves the prospects of future research testing novel hypotheses generated by well-informed philosophers of cognitive science, promoting valuable interdisciplinary interactions to combat the inbreeding of cladistic ideas.

¹¹⁴ Psychological explanation is primarily a matter of functional analysis, answering the question "how does *x* work?" not identifying proprietary laws, cf. (Cummins, 2000). Presently, our *x* is temporal perception.

¹¹⁵ This skeptical position agrees that humans and other creatures have means for representing temporal properties of and relations between external stimuli, but it denies that such temporal representation entails temporal perception. See Le Poidevin (2007) for an extended defense of this brand of skepticism. I argue at length against Le Poidevin's position in Chapter 3. Nevertheless, there is a long lineage of philosophers taking time perception seriously, albeit for different reasons and in the service of reaching various different conclusions: Aristotle, Augustine, Locke, Kant, Husserl, Broad, Russell, Heidegger, Merleau-Ponty, Mellor, Dainton, etc.

One explanation is that the purported experience of motion is a function of the temporal relations between adjacent perceptions, the degree of representational overlap between the contents of those perceptions, and some cognitive post-processing involving working memory which utilizes the series of atomistic “snapshots” that our sensory systems capture at each passing moment to generate non-perceptual representations of temporally extended events.¹¹⁶ According to the atomist, my discrete perceptions of the baseball happen in such rapid succession that the interval between them is undetectable, making it seem as though my experience is extended and continuous.

I am inclined to agree that working memory plays an important role in temporal representation, as I discuss below, but deny that perception is temporally atomistic in the way just described. Instead I advocate for a version of Content Extensionalism, holding that we perceive the temporal relations between non-simultaneous events in virtue of targeting and representing temporally extended content. I perceive the baseball moving by representing extended segments along its trajectory and the relations that obtain between its successive locations and orientations in spacetime. I also hypothesize that such perception involves sampling the environment at multiple temporal scales (e.g. tens of milliseconds, hundreds of milliseconds, seconds), prediction-correction feedback cycles to continuously update projective estimates of ongoing stimuli, and integrating information across various subsystems. On my view, perceptual experience does not consist solely in passive detection of the environment, but involves active sampling, predicting, and updating representations in real time.

Whether or not such neurocognitive processes posited by my preferred model count as perception is merely a question of conceptual boundaries, and not a particularly deep disagreement,

¹¹⁶ I evaluate and argue against the atomist’s error theory for explaining purported experiences of motion at length in Chapter 2, “Modeling Constant Motion Perception.”

since both extensionalists and atomists agree that we do seem to have such experiences, perceptual or not.¹¹⁷ No parties to the debate deny the phenomenology, rather they dispute what explains our temporal experiences and representations. More substantive and unsettled questions concern how such temporal representations are generated, whether our sensory systems sample the world in atomistic time-slices or at multiple temporal scales, how temporal information is integrated, and what mechanisms realize these capacities. Empirical research has the potential to decide between the diverging answers given by the opposing philosophical positions like atomism and extensionalism or, more conservatively, provide evidence that favors the proprietary hypothesis of one model over another.¹¹⁸

Furthermore, I suggest that philosophical analysis of the experimental findings may generate new hypotheses and predictions for a particular scientific theory, or offer critical arguments to help rule out the plausibility of particular competing models. This is an important role for the philosopher to play in the advancement of cognitive psychology and neuroscience, just as the cutting-edge work of scientists should inform contemporary philosophy of mind.¹¹⁹ To illustrate this interdisciplinary upshot, I make a case for philosophical contributions to the fertile domain of temporal processing where there remain many contenders and no consensus on the exact mechanisms that realize temporal perception.¹²⁰ In the following, I pay particular attention to the research concerning duration perception, including the models on offer and the hypotheses that link those models to real physical systems.

¹¹⁷ Chuard agrees that the differences between narrow, purely sensory, accounts of perception and less restricted accounts like mine are not substantive and should not be the focus of the debate (cf. 2011: 8 fn10).

¹¹⁸ Some evidence *E* favors H1 over H2 if *E* increases the ratio of the posterior probability of H1 to the posterior probability of H2.

¹¹⁹ Given that my future funding is not contingent on the success of any particular model, I can maintain an impartiality in my evaluations of competing models not enjoyed by scientists with considerable time and resources invested in their models.

¹²⁰ See Ivry & Schlerf (2008: 273-80) and Wittmann (2009: 1955-67) for detailed discussion of the competing models, reviews of the relevant experimental paradigms, and outstanding problems for each candidate.

In §4.2, I specify a target range of temporal phenomena salient to understanding perceptual cognition, and motivate the *multi-scale sampling* (MSS) hypothesis that sensory subsystems sample information at multiple rates, i.e. shorter and longer sampling periods. To continue building a case for MSS and its connection to content extensionalism, in §4.3, I argue that both behavioral and neurophysiological data support the hypothesis that nervous systems process temporal information by sampling stimuli signals at shorter and longer durations. I first consider evidence for sampling in the tens of milliseconds-range based on the performance limitations of our perceptual systems which constrain the lower-bound threshold of target phenomena for temporal perception in humans, i.e. system limitations determine how finely we can discriminate the temporal order and duration of external stimuli. In §4.4, I advance the hypothesis that working memory capacity is one factor that constrains the upper-bound limit on the temporal range of phenomena that can be perceived. Experimental data, I maintain, favors the hypothesis that temporal perception is constituted by multi-scale sampling and integration, over a single-sampling rate hypothesis implied by the atomistic “snapshot” model.

In order to articulate a methodology for evaluating competing models within the mind sciences, in §4.5, I borrow insights about scientific representation from the structuralist program in the philosophy of science¹²¹ and endorse a form of *constructive realism*—the view that scientific theories are best understood as (a) families of models and (b) hypotheses that specify the respects and degrees in which a model represents some real physical system.¹²² I explain and proceed to implement constructive realism by offering an initial exploratory evaluation of the ways empirical

¹²¹ Cf. Suppes (1956, 1967), Sneed (1971), Suppe (1974), Stegmüller (1976), Balzer, Moulines, and Sneed (1987), Giere (1988), Bickle (1998)

¹²² See Giere (1988: 92-110, 1999: 174-199) for an extended defense of constructive realism as a doctrine about scientific models and hypotheses representing real systems. The natural foil is the constructive empiricism of van Fraassen (1980, 1982), in which scientists construct models but only the observable aspects of real systems incur ontological commitments, giving an anti-realist interpretation of unobservable posits (e.g., forces, spin, charge).

evidence are marshaled in favor of the main competing models of duration perception, especially the “dedicated internal clock” and “intrinsic neural signature” classes of models. I argue that philosophers of temporal perception have a vested interest in remaining apprised of the ongoing empirical work on temporal processing, and conclude by highlighting some possible avenues for future interdisciplinary collaborations.

4.2. Multi-scale Sampling and Integration

A wide range of timescales are physiologically relevant to the maintenance of living systems, but only some of these scales represent candidates for perceptible durations. Michael Mauk and Dean Buonomano (2004) suggest that the human organism processes temporal information over a scale spanning, at least, 12 orders of magnitude, from fast neural processes like “axonal delays” necessary for sound to travel from one ear to the other ($\approx 10^{-3}$ - 10^{-2} ms) to slower biological rhythms on orders of hours and days ($\approx 10^6$ - 10^9 ms) such as the “ultradian”, “circadian”, and the “infradian” rhythms that auto-regulate important physiological processes including appetite, sleep-wake, and menstrual cycles.¹²³ While these slower rhythms on the order of hours and days presumably are important for a complete understanding of physiology, they do not bear directly on the present issue of temporal perception, barring further argument to the contrary.¹²⁴ Although I certainly can experience the effects of fatigue and drive to sleep associated with dips in the circadian cycle or the energized alertness associated with its peaks, it is implausible that I can

¹²³ For classic chronobiology research see Aschoff, (1965, 1998); Scheving et al., (1974); and Winfree (1980), for a molecular genetic basis of circadian rhythms see King & Takahashi (2000).

¹²⁴ I leave open the possibility that these slower biological rhythms do influence temporal perception in important ways, but that is beyond the scope of the present investigation. For example, a recent study by Meissner & Wittman (2011: 289-297) indicates that interoceptive awareness of one's cardiac rhythms is correlated with more accurate timing in the range of seconds. That is, subjects that are better at perceiving their heartbeat are better at reproducing durations on the scale of seconds. For present purposes, I bracket the role of autonomic function in the perception of time intervals in the range of seconds.

perceive the entire 24-cycle. Likewise, I can hear various motifs, melodic phrases, chord progressions, and modulations in key during different phases of a musical performance, but perceiving an entire 15 min movement is beyond the range of my perceptual acuity.

The scope of the present analysis ought to be limited to the intervals that, at least in principle, correspond to perceptible durations. Such a limitation in scope is not without precedent. Scientific investigations of human temporal perception, including the processes which realize such perception, typically target a more limited range of interval phenomena ($\approx 10^{-1}$ - 10^4 ms)—not too brief, but not too long.¹²⁵ Much neurophysiological modeling and experimentation focuses on two distinct “temporal integration windows”, one at a short sampling period (20-50ms) and one at a longer sampling period (150-300ms); especially work in auditory perception (Plack & Moore 1990; Plack & Viemeister 1993; Theunissen & Miller 1995; Hirsch & Watson 1996; Poeppel 1997, 2003; Warren 1999; Boemio et al. 2005). Additionally, both philosophers and psychologists appeal to temporal gestalts in the range of 2-3s in phenomenological descriptions and explanations of perceptually mediated behaviors.¹²⁶ Positing temporal integration windows and gestalts suggests that nervous systems process continuous information from the environment by quantizing it into discontinuous chunks or “chunking”.

Despite capacities to sample stimuli on multiple sub-second scales, there are limits on how brief sensory information can be chunked. If we sample the world in the range tens of milliseconds, why not in the range of microseconds or nanoseconds? First, while it is metaphysically possible

¹²⁵ For comprehensive reviews that indicate the wide agreement regarding the salience of intervals in the tens and hundreds of milliseconds range, see also Buonomano & Karmarkar (2002: 42-51), Wittman (2009: 1955-67), van Wassenhove (2009: 1815-30), Merchant et al. (2008: 939), Eagleman and Paryadith (2009: 1841-51). The agreement is particularly notable because the various researchers cited advance opposing models of temporal processing, yet agree on the range of phenomena under investigation and design their experiments accordingly.

¹²⁶Cf. Clay (1882), James (1890: 603), Broad (1923: 350), Boring (1949), Myers (1971), Pöppel (1978, 1988) Ruhnau (1994, 1995), Varela (1999), Dainton (2000, 2008), Kelly (2005ab), Lockwood (1989, 2005), Soteriou (2007), Hoerl (2009) and Phillips (2010).

that some perceptual system could sample stimuli at incredibly fast rates, and computer technology has produced processors that cycle at such rates, but mammal brains are not equipped with the hardware to execute such tasks. A single neuron in the human brain takes 1ms to fire and return to a resting state (Coon 1989), so it is preposterous to expect that populations of neurons firing could somehow sample sensory information at rates faster than individual neurons can fire. Second, if our perceptual systems were to sample at such fast rates, then we would be able to discriminate much finer-grained phenomena like the individual beats of a mosquito's wings. But, we cannot; there are well-confirmed performance limitations on our capacities to discriminate sensory information. In the next section (§4.3), I describe the evidence for these lower-bound thresholds, and argue that the performance limitations with respect to sub-second processing should directly constrain models of temporal perception. Prior to doing so, let us examine how the forgoing discussion bears on the debate between extensionalism and atomism.

Since content extensionalism claims that perception targets and represents temporally extended contents, the model hypothesizes that nervous systems somehow function to sample incoming signals and chunk information within extended temporal windows. According to this extensionalist postulation, sensory subsystems, such as those processing auditory signals, sample environmental stimuli at multiple scales, continuously processing and integrating the information across distinct temporal grains in order to generate perceptual representations of ongoing extended events. Such a hypothesis predicts that there are subsystems sampling signals at different rates in order to identify temporal patterns in dynamic stimuli (e.g. syllabic processing, rhythms, chord progressions, motion trajectories) enabling real-time anticipation of future states. Call this the 'Multi-Scale Sampling' hypothesis.

Multi-Scale Sampling (MSS): The hypothesis that (i) distinct perceptual subsystems sample sensory signals at multiple interval scales, (ii) such subsystems sample the same sensory signals, in parallel, at distinct rates, (iii) multi-scale sampling enables the system to reliably anticipate future states of a dynamic target (e.g., watching a bird in flight, listening to a melody, hitting a baseball).

MSS is a possible link between the theoretical model of content extensionalism and the physical systems that realize the function of representing temporally extended content in perception. Extensionalism claims that we perceive dynamic targets like melodic phrases in virtue of representing temporally extended contents, and MSS offers a functional explanation of how that works. If MSS is the case, we should expect to find evidence for distinct sampling mechanisms. Empirical support for MSS would, in turn, provide reason to prefer extensionalism as a model of temporal perception, if atomism were not also compatible with MSS.

Can atomism avail itself of MSS? Atomism posits a series of discrete perceptual snapshots, which is compatible with a short sampling period (20-50ms), but is at odds with the proposal of MSS that distinct subsystems also process signals at longer sampling period enabling perception of temporally extended stimuli. If atomism is incompatible with longer sampling periods, generating perceptual representations of non-simultaneous events, then MSS is unavailable to the atomist. Atomism does have the resources, however, to propose an alternative hypothesis explaining away the evidence for longer sampling periods.

An atomist might claim that the contents of longer integration windows are reducible to and composed of brief atomistic perceptions. This seems like a natural move, because atomism is an overtly mereological model according to which non-perceptual representations of longer durations are composed of atomistic snapshots as parts (cf. Chapter 2, Chuard 2011). For the atomist, purported evidence of temporally extended chunking is explained in terms of some other cognitive

function combining series of successive perceptions with a significant degree of representational overlap, not extended perceptual sampling. Call this the ‘Atomistic Sampling and Combination’ hypothesis.

Atomistic Sampling and Combination (ASC): The hypothesis that (i) perception samples sensory signals at a single rate to generate atomistic experiences, and (ii) other cognitive mechanisms combine and encode the temporal relations between those successive perceptual experiences.

On this alternative explanation, we perceive and encode the brief chunks in succession and some other downstream process integrates those chunks and makes the integrated content available for representation in memory. We do not perceive longer durations, but we can represent them in virtue of successively perceiving each of the atomistic parts. If ASC were the case, then we would expect to find evidence that mechanisms integrating over longer temporal windows are downstream consumers of the information processed by faster sampling subsystems. I argue that ASC is undermined by research indicating that distinct neural populations oscillating at different frequencies sample the same signal at distinct rates.

As evidence supporting MSS, temporal information on multiple time scales are relevant to processing speech signals (Rosen 1992). Short-duration sampling (20-50ms) enables encoding of formant transitions in stop-consonants (Liberman et al., 1967), whereas sampling at 150-300ms is associated with encoding syllables essential for speech recognition (Greenberg 1998) and speech acquisition (Mehler & Hayes 1981, Eimas 1999). For instance, when I hear someone utter the sentence, “Beware of black cats,” my auditory cortices are sensitive, among other things, to the formant transition resulting from the stop-consonant ‘b’ in ‘beware’ and ‘black’ as well as the syllables ‘be’, ‘ware’, ‘of’, etc. I am able to recognize and encode speech in virtue of sampling the

auditory signal at different rates. If ASC were true, then my auditory system would sample the speech signal one sound at a time ‘b’-‘e’-‘w’-‘a’-‘re’ and only combine them after the fact.

Poeppel (2003) and Boemio et al. (2005) present compelling neuroimaging data indicating that neural populations of auditory areas in the left and right hemispheres preferentially extract temporal information at distinct timescales, where the left hemisphere samples at short 20-50ms intervals and the right hemisphere auditory areas sample signals at the rates corresponding to longer temporal integration windows in the range of 150-300ms. If the auditory subsystems asymmetrically sample the same incoming auditory signals at distinct rates, then the longer windows are not merely composites of the shorter windows, contra what the atomist’s ASC hypothesis would lead us to expect. Thus, we have some evidence in supporting (ii) of MSS, and reason to doubt the tenability of ASC particularly for auditory processing.

Another strategy available to the atomist is to simply concede MSS, but deny that empirical evidence about sensory signal sampling has any bearing on the viability of atomism. The atomist might claim, “Atomism is a theory about perceptual representation and its proper target is conscious experience not neural processing. The brain might be doing all kinds of processing of which I am unaware, but that does not preclude the possibility that I experience each moment successively. After all, this complex sampling and integration might result in regular conscious snapshots of the world in rapid succession; conscious experience is a product of neural processing but not identical to it.” I am suspicious of any move that tacks on another auxiliary hypothesis to rescue a model from disconfirmatory evidence. In this case, the atomist postulates that conscious perceptions are successive outputs of integrated neural processing (however, that happens), in order to block the inference that longer sampling periods enable perception of non-simultaneous events. This move is similar to how Ptolemaic astronomers posited complicated epicycles to

preserve circular planetary orbits, in light of observing retrograde motion of planets that conflicted with their earlier predictions. Additionally, this dodgy strategy excuses atomism from answering the present empirical challenge to the theory and, in turn, makes the model explanatorily otiose. Maybe atomists are not in the business of explaining how their model could be physically realized or how physical process generate perceptual representations. If so, all the worse for their business.

The forgoing discussion provides sufficient reason to focus on the processing of temporal information on the orders of magnitude that correlate with phenomena that we *seem* to perceive together: hearing a rapid arpeggio played by a guitarist, seeing a raptor in flight, catching a ball, understanding a sentence token as it is spoken, etc. These sorts of phenomena spanning brief intervals in the sub-second range up to no more than a few seconds in duration are the bread and butter of temporal perception, because such events are seemingly within the window of present experience (see Ch.1) and are associated with the temporal integration windows borne out by evidence from cognitive science. By contrast, hearing the entire song played by the guitarist, watching a raptor catch and kill its prey, playing a game of baseball, or engaging in a lengthy dialogue are significantly longer events that cannot be directly perceived as a whole—although we can effectively represent events of longer duration.

For an example of representing longer complex events, a spreadsheet scorecard and conventional notation enables a baseball spectator to represent the diverse events that occur over the course of a game, since individual cells are marked to represent the history of an offensive player for every at-bat—coding the number of pitches taken, balls or strikes, whether the batter reached base or were put out, and by which defensive position player(s), whether the runner advanced on a hit or by stealing, etc. The batter/runner histories during each half-inning, and the individual events within those histories (e.g. a sequence of pitches), constitute the order of a

particular game. A scorecard is a tool for thinking (cf. Dennett 2000), a mind-tool enabling representation and analysis of the complex structure of events in a baseball game, what happened when and by whom, and in relation to what other happenings. By recording the history of a game onto a scorecard, a scorekeeper converts perceptual information from her ongoing observations of a game into an external portable representation; the scorekeeper “makes marks in the world in order to cut down [her] cognitive load” (Dennett 2002: 96).

To put this example in terms of information processing, a scorekeeper offloads an intractable long-term memory task into the scorecard (i.e. remembering the details of every batter history that happens over the course of a game) by taking a rich manifold of visual and auditory information (in analog form) and digitizing it into a readily accessible digital format. Fred Dretske (1981) takes the analog-to-digital conversion to be the fundamental function of mobilizing perceptual information for cognitive mechanisms, putting it into a format that the consumers of the information can exploit for various tasks. The scorecard is an external analog-to-digital converter that reduces the cognitive load on the scorekeeper's memory in exchange for dedicating more resources to perception. This enables the scorekeeper to more attentively observe the presently occurring events—actively converting incoming analog sensory information into digital form for selective cognitive use. Likewise, given MSS, sensory subsystems that sample analog signals on distinct temporal scales are digitizing the information in order to make it accessible to be utilized by downstream mechanisms for representing ongoing and complex events.

Necessarily, there is information lost in the digitization of analog information, since, in the process of modeling the data, a given representational scheme will make forced assumptions about the accidental and non-accidental features of the world, ignoring the former and fixing the latter. Dretske describes his information processing model of perception, as follows:

Seeing, hearing, and smelling are different ways we have of getting information about *s* into a digital-conversion unit whose function it is to extract pertinent information from the sensory representation for purposes of modifying output. It is the successful conversion of information into (appropriate) digital form that constitutes the essence of cognitive activity...Cognitive activity is the *conceptual* mobilization of incoming information, and this conceptual treatment is fundamentally a matter of ignoring differences (as irrelevant to underlying sameness), of going from concrete to abstract, of passing from particular to general. It is, in short a matter of making the analog-digital transformation. (Dretske 1981: 142).

In some ways, Dretske's analog-digital transformation realizes the same function as *synthesis* in Kant's model of cognition. Namely, the function of selecting and integrating sensory information, in order to generate a perceptual representation of events in the world. Consider the following passage, where Kant introduces the active capacity of synthesizing a sensible manifold:

The synthesis of a manifold, however, (whether it be given empirically or *a priori*) first brings forth a cognition, which to be sure may initially still be raw and confused, and thus in need of analysis; yet the synthesis alone is that which properly collects the elements for cognitions and unifies them into a certain content; it is therefore the first thing to which we have to attend if we wish to judge about the first origin of our cognition. (A77-8/ B103)

Synthesis is the function of processing and integrating multiple sources of sensory information into a unified representation. For example, if I hold and observe a toad while it croaks “ribbit,” my auditory system enables me to hear the sound the toad emits, my visual system enables me to see the throat swell prior to the croak, and I feel the toad’s diaphragm expand and contract, in addition to feeling the temperature and texture of the toad’s skin. Even this somewhat simplified example of holding a toad shows that sensory information is being picked-up and processed across multiple channels (i.e. auditory, visual, tactile, olfactory) simultaneously, and yet my perceptual system and

subsystems continuously function to select and combine the information into a coherent representation of the toad croaking in my hand.

For Kant, this initial synthesis of analog sensory information is a necessary condition for cognition, by which the further synthesis of understanding represents the perceptual information according to concepts. Without this synthesizing function, or analog-to-digital conversion, the sheer amount and complexity of incoming analog information about the environment would overwhelm perceptual processing and make the problem of representing the world intractable. For Kant, synthesis is a necessary integrative function, without which ongoing perceptual representation of the world would be impossible; and, as such, a proper analysis of our capacity to cognize the world should begin with understanding this integration.

While there are certainly differences in the aims and theoretical motivations between Kant's synthesis and Dretske's analog-digital transformation, they share an emphasis on the integrative function which makes available sensory information via perceptual representations by selecting some bits as salient, discarding other bits as irrelevant—taking an analog flood of information across multiple channels and converting them into a digital form more easily exploited by other cognitive systems. I argue that the MSS hypothesis helps to explain how we digitize the information, by selecting and sampling the environment at multiple temporal scales.

First, I argued that content extensionalism and atomism differ with respect to hypotheses concerning how perceptual systems select and sample ongoing sensory information. Second, I motivated MSS and made a case for its connection to content extensionalism. Finally, I compared Dretske's analog-to-digital conversion and Kant's active synthesis in order to explain the necessary role of sampling and integration for processing sensory information and making perceptual representation possible. To further support MSS, in the following subsections, I both

delimit the lower-bound thresholds on interval processing and integration for temporal perception (§4.3) and hypothesize that the upper-bound threshold of temporal processing and integration in direct perceptual awareness is a function of working memory capacity (§4.4).

4.3. Delimiting Lower-bound Thresholds for Temporal Perception

The contingent limitations of our perceptual processing systems constrain the range of temporal intervals relevant to our cognitive capacity for temporal perception. For the sake of explication, I treat cognitive capacities as complex dispositional properties for processing particular kinds of information, although specifying the conditions under which a capacity is manifested is often difficult.¹²⁷ Fortunately, time processing is tractable because we possess plentiful data indicating that certain precipitating conditions reliably cause certain responses. In this way, behavioral regularities help delimit the upper- and lower-bound thresholds of temporal perception. In addition, the neurophysiological research I cited in the previous section related to the short-duration temporal integration window of 20-40ms, as one of the sampling rates predicted by MSS, provides some explanation of the lower-bound thresholds. I begin with the lower-bound thresholds which stimuli must exceed in order for us to register and process the temporal relations of succession, order, and simultaneity.

The lowest of these thresholds is the *fusion threshold*, which denotes the briefest time separation between two stimuli of a single sensory modality to be discerned as distinct stimuli. Stimuli presented too closely together, below the fusion threshold, will be represented as a single stimulus. Thus, the fusion threshold indicates the minimum interval between stimuli, called the 'interstimulus interval', that is necessary for perceiving distinct stimuli *as* distinct. Experimental

¹²⁷ Cf. Marr (1982) and Cummins (2000).

paradigms use transient stimuli (e.g. clicks, flashes, noise bursts, taps) to establish that the fusion threshold is 2-3ms for auditory stimuli,¹²⁸ 10ms for tactile stimuli, and 20ms for visual stimuli.¹²⁹ We can state these fusion thresholds as dispositions: If a subject were administered two taps on the arm <10ms apart, then, *ceteris paribus*, the subject would only perceive one tap. A corresponding disposition can be iterated for the fusion threshold for each sensory modality, since perceptual subsystems specialized for processing different types of perceptual information also differ with respect to temporal acuity. Simply reflecting on the experience of listening to complex music reveals that we are capable of finely discriminating auditory stimuli, whereas the greater fusion threshold for vision—the coarser temporal resolution of visual stimuli—is illustrated when one observes a hummingbird feeding at a flower and sees only blurry motion instead of its individual wing beats.

A second threshold is the *order threshold* which represents the minimum duration at which two events can be perceived in their correct order; when using transient stimuli the order threshold across all modalities is around 20-40ms.¹³⁰ If a subject were presented two tones >2ms and <20ms apart, then, *ceteris paribus*, the subject would hear the two tones as non-simultaneous, but could not discern which tone occurred first. The subject represents one tone happening before the other, however, the auditory system is unable to exploit the perceptual information carried by the representation about the order of the non-simultaneous tones. This is an instance of what Blackmon et al. (2008:195-207) call ‘unexploited content’, which is information available in or carried by a representation that the system is unable to exploit. The reason the perceptual system is unable to exploit the information has to do with the tradeoff between faster sampling and high frequency

¹²⁸ Exner (1875), von Békésy (1936), Elliott & du Bois (2017)

¹²⁹ Landis (1954)

¹³⁰ Hirsh & Sherrick (1961), Hirsh & Fraisse (1964), and Fraisse (1984)

resolution. The ability of listeners to resolve and integrate rapid frequency changes on the order of 20-40ms only allows for a resolution of 40 Hz or less, whereas a longer temporal integration window of 200ms enables the auditory system to distinguish very small frequency changes on the order of 5-10 Hz (Poeppel 2003: 250). So, the ability to discern such rapid auditory stimuli, yet not exploit temporal order information contained in the representation, is a function of the tradeoff in resolving power for the ability to represent rapid frequency changes in perception.

Related to this tradeoff between integration and resolution, the order threshold becomes much larger as the stimuli become more complex. For example, in baseball, on a force play, if the baseball and the base-runner were to arrive at the base at different times, but the interstimulus interval between the visual stimuli is below the umpire's order threshold, then the umpire would perceive the events of the ball-arriving and runner-arriving as non-simultaneous, but be unable to discern which event happened first. Due to the complexity of tracking two distinct trajectories toward the base, the order threshold in these cases is much greater than the 20-40ms estimate for simple stimuli.

A third relevant threshold is the *simultaneity threshold* which represents the minimum interstimulus interval for two stimuli to be perceived as successive, below that threshold two stimuli are perceived as simultaneous. When using transient stimuli the simultaneity threshold is approximately 20-30ms across modalities.¹³¹ If a subject were administered two taps on the arm >10ms and <20ms apart, then, *ceteris paribus*, the subject would feel the two taps as distinct yet simultaneous. Since the fusion threshold for tactile stimuli is lower than the simultaneity threshold, I can perceive the arm taps *as* distinct, without perceiving that the taps as successive. For vision, however, the fusion, order, and simultaneity thresholds are roughly the same, which implies that

¹³¹ Kanabus et al. (2002), Fink et al. (2006), Wittman (2009).

if a normal subject can register two distinct visual stimuli then the subject should also be able to discern their order. By contrast, for audition the simultaneity threshold is around 10ms, but the order threshold is 20ms, so one can discern that two stimuli are successive without being able to judge which stimulus was presented first.

I take these lower-bound thresholds to further support the idea that processing on the magnitudes of tens and hundreds of milliseconds are integrated in perception, one feature of multi-scale sampling. MSS predicts that some sampling rates can rapidly resolve frequency changes but at a lower resolution, which is evidenced by the limitations defined by the fusion, order, and simultaneity thresholds. If our perceptual system passively took in big ‘gulps’ of temporal information with a much higher resolution, without multi-scale processing and integration, then it would be unlikely for us to represent rapid frequency changes and represent sub-second phenomena as required for speech comprehension and musical appreciation.

4.4. Delimiting Upper-bound Thresholds: Temporal Integration Windows, Reproduction Tasks, and Working Memory

Temporal processing on the scale of one to tens of seconds is also hypothesized to play a critical role in the integration of sensory information in the elaboration of a perceptual representation.¹³² As previously noted, the range of a few seconds has phenomenological relevance, because we seem to directly perceive events unfolding within intervals of a few seconds. Ernst Pöppel (1978) estimates that the temporal integration window for conscious perception is $\approx 2\text{-}3\text{s}$, which roughly approximates the philosophical notion of the ‘specious present’.¹³³ Beyond

¹³² Cf. Wackerman & Ehm (2006: 482) and van Wassenhove (2009: 1818)

¹³³ Philosopher Michael Lockwood (2005: 379-80) uses ‘time window’ to denote the scales of duration relevant to conscious experience. For various accounts of the specious present, cf. Clay (1882), James (1890), Broad (1923), Boring (1949), Myers (1971), Pöppel (1978, 1988) Ruhnau (1995), Varela (1999), Dainton (2000, 2008), Kelly

the apparent phenomenology, a principal source of evidence for the temporal integration window comes from behavioral studies that employ *temporal reproduction* tasks to assess duration perception in human subjects. Before examining the highly constrained experimental task, a familiar example will be useful for illustrating the phenomenon.

Imagine a drum lesson in which the instructor demonstrates a simple rhythm in 3/4 time on a snare drum and instructs the student to reproduce the same rhythm. The student's task is one of *temporal reproduction*, i.e. a task in which a temporal structure is first perceived and then replicated. Drumming is a skillful behavior that illustrates the abilities of humans to perceive the temporal structure of environmental stimuli, regulate motor action in accord with temporal patterns, and reproduce those patterns. The timing processes necessary for execution of complex coordinated behaviors like drumming are very complex, but are presumably constituted by more basic mechanisms for perceiving duration and order. A detailed look at the temporal reproduction paradigm will assist in evaluating its measurement of duration perception.

In a temporal reproduction task, participants are instructed to reproduce a stimuli (e.g., tones) of various target durations (e.g., 8s, 14s, 20s) by pressing a key when they judge that a second comparison stimulus has reached the same duration as the probe stimulus.¹³⁴ In an auditory experiment, trials typically begin by presenting participants with a probe tone at one of the target durations (encoding interval), followed by a silent pause (interstimulus interval).¹³⁵ After the pause

(2005b), Lockwood (1989, 2005), Soteriou (2007), Hoerl (2009) and Phillips (2010). See also Gallagher (1998: 26-31) for a discussion of the terminological and philosophical perplexities of the specious present.

¹³⁴ Some versions of this task instruct participants to press a key to start the comparison stimulus and press it a second time to halt the stimulus, this additional motor task has significant effect on the timing task so it is avoided in recent temporal reproduction task experimental designs. See, for example, Eisler & Eisler (1992), Meissner & Wittmann (2011), and Wittmann et al. (2010)

¹³⁵ The length of the interstimulus interval can vary in experiments to adjust for variance in participant response times, so that investigators are able to ensure that the total duration for each run of trials is identical for each participant (cf. Meissner & Wittmann, 2011). For example, each run consists in six trials on each of the three target durations for a total of eighteen trials presented in random order, varying the interstimulus interval to adjust for response variance allows for each run to have same duration (e.g., 14 min.) for each participant.

participants are presented a comparison tone, and they are instructed to halt the tone by pressing a key when they judge the comparison duration (reproduction interval) to match the target duration. Since temporal reproduction tasks are taken to be a standard measure of perceptual timing accuracy, and perceptual timing is supposed to be an implicit automatic process, counting strategies by participants would confound the data. Thus, participants are instructed not to count, and secondary cognitive tasks are typically used to further preclude counting strategies.¹³⁶

Numerous studies indicate human performance on temporal reproduction tasks for stimuli falling within the range of the temporal integration window of 2-3s is highly accurate, whereas longer intervals are substantially and systematically underestimated.¹³⁷ Temporal reproduction accuracy is robust across subjects for interval stimuli within the temporal integration window. For example, in a psychopharmacological study, Marc Wittmann and colleagues (2007) used the temporal reproduction task to measure the effects of the hallucinogen psilocybin on duration perception and found that subjects receiving both low and high doses of psilocybin performed, on average, just as good on temporal reproduction tasks for intervals <3000ms as control subjects receiving a placebo.

This evidence of reliable timing within the temporal integration window is significant, since subjects under the influence of psilocybin exhibit a wide range of dissociative and hallucinatory symptoms. For intervals exceeding the temporal integration window (>3000ms), however, control subjects far outperformed hallucinating subjects. The researchers took this to indicate that the

¹³⁶ For example, a secondary memory task can consist in presenting an image of 4 simple shapes or numbers before the onset of the probe tone, and instructing participants to remember those shapes or numbers. After the comparison tone is halted, a shape or number is presented and the participant is asked whether or not that shape or number is one of the 4 that were presented initially. The additional load on memory by the distracter task prevents participants from trying to cheat the prohibition on counting strategies. Some studies restrict the target durations of reproduction task to less than 2s (e.g., 500ms, 1500ms, 2000ms) to preclude counting strategies altogether, since such strategies are ineffective in the sub-second range.

¹³⁷ Cf. Block & Zakay (1997), Ulrich et al. (2006), Ulbrich et al. (2007), Wittmann et al. (2007), van Wassenhove et al. (2011)

serotonin agonist, psilocybin, does not directly interfere with dedicated temporal processing mechanisms, but interferes with attention or working memory required for representing and encoding durations of longer intervals (2007: 61). This study helps us begin to see the relevance of working memory and its function in temporal processing for durations exceeding the upper-bound threshold of the temporal integration window.

A plausible hypothesis for why the temporal integration window is the upper-bound threshold of direct temporal perception, is that working memory capacity sets the upper-bound of immediate perceptual experience at $\approx 2\text{-}3\text{s}$, because the updating of working memory is necessary to track a dynamic environment. Differences in working memory capacity offer a basis of the variability of the temporal integration window between subjects. In some studies (Ulbrich et al. 2007; Wittmann et al., 2007), all subjects prior to the temporal discrimination task, are given the Corsi-block test; a test consisting of nine white blocks that light up in a sequential random order, where subjects are asked to identify the order in which the blocks light up, and the number of blocks increases with each accurate performance.¹³⁸ Performance on the Corsi-block test is a good predictor for performance error on temporal reproduction tasks. That is, subjects that score lower on the Corsi-block test have a systematically greater margin of error in temporal reproduction tasks where the target stimulus has a duration of greater than 2500ms, as compared to high-scoring subjects. So, it is reasonable to conclude that the duration of a subject's temporal integration window is strongly correlated with their working memory capacity. Does this entail that temporal perception is a direct function of memory? No, it only indicates that the upper-bound of the temporal integration window is somehow constrained by working memory capacity. The evidence favors the hypothesis that this constraint is a regulatory feature of the memory system, such that buffering and encoding of

¹³⁸ This task is modeled in many so-called 'memory' games marketed to the general public.

perceptual content occurs on regular cycles, the periodicity of which is determined by how much information the perceptual system can process at a given time and how that information is represented in working memory.

Recall that atomist models often emphasize the role of memory in accounting for putative experiences of temporally extended events. One might think that the foregoing discussion of the temporal reproduction paradigm and the experimental results favor the atomist's mereological conception that purported temporal experiences are a result of combining series of static perceptions successively, and with the aid of working memory. Note, however, that content extensionalism does not deny that working memory plays important roles in cognition, especially when tracking events over longer intervals, e.g. watching a play or engaging in conversation. That working memory constrains the upper-bound of the temporal integration window is no great boon for atomism, because it does not favor one theory over the other.

As opposed to vindicating the atomist's explanation, the experimental evidence from the temporal reproduction paradigm weighs slightly against their model. The highly accurate performance of subjects on temporal reproduction tasks within 2-3s intervals, even across subjects with impaired working memory, suggests that perceiving brief, yet temporally extended events, within such integration windows does not rely on mediation from working memory. Content extensionalism and MSS predict that sensory systems sample the environment at multiple scales up to and including the 2-3s integration window, enabling perception of temporal relations between non-simultaneous events occurring within that interval. So, once again, atomism is in a worse position to explain the empirical evidence than content extensionalism. I now move to defend a position within the philosophy of science that has informed my approach to explanation throughout the project.

4.5. Constructive Realism: A Model-based Approach to Temporal Perception

At the outset, I argued the empirical work should inform philosophical theories of temporal perception and possibly help decide between competing hypotheses linking theoretical models to the world. Likewise, I hold that philosophers might play valuable roles in the advancement of science, in terms of evaluating competing models of how temporal perception is physically realized in nervous systems like ours. To enter into this interdisciplinary project, I here outline a framework for understanding scientific theories and specify the desiderata by which assessment of competing models should proceed.

How does temporal perception work? What cognitive mechanisms make temporal processing possible? The preferred way to go about answering these questions in cognitive science is to develop a model, or a family of models, intended to represent the structures and mechanisms of the target system. The various competing models aim to show how neural mechanisms process and encode temporal information in the service of generating representations that preserve different aspects of the temporal structure of a specific event, such as the event's duration, interval, and order. This brief summary is an oversimplification, however, and a more careful understanding of model-building practice in cognitive science is required.

My focus on models and modeling is a methodological choice, made in order to emphasize the important roles that such representational media play in attempting to understand, explain, and make predictions about systems of temporal perception—highlighting the continuity in method between philosophy and scientific practice.¹³⁹ Models are particular kinds of 'mind-tools', which

¹³⁹ See Godfrey-Smith (2003) for an argument that large-scale systematic philosophical theorizing is best understood as model-building. Likewise, Laurie Paul (2012) argues that metaphysical theories are classes of models, which employ experience, intuition, thought experiments, and logical analysis in the construction and evaluation of such models. Paul thinks that metaphysics has a distinctive subject matter from science, but not a distinct methodology. I

help to make epistemic problems tractable (Dennett 2000). Humans are adept model builders, and when investigating a complex domain, as we often do in both philosophy and the sciences, an effective method is to proceed by fixing some structural components and functional relations within a modeled system in order to make inferences about how the system will behave under various transformations and thereby seeing how well that fits with our observations and interventions, among other data.

I endorse a form of *constructive realism* and hold that comprehensive theories of temporal experience are constituted by both (a) families/classes of models, and (b) hypotheses linking the models to the phenomena and the cognitive systems of which they are intended models.¹⁴⁰ Broadly understood, models are humanly constructed entities developed and deployed to represent and explain features of the world, hence the 'constructive' dimension of this meta-theory. As for the 'realistic' dimension, the hypotheses of a theory function to specify the respects and degrees to which a given model represents some real physical system, “asserting a genuine similarity of structure between models and real systems without imposing any distinction between 'theoretical' and 'observational' aspects of reality,” (Giere 1999: 168). Hypotheses provide propositional interpretations of a model by saying what the model shows, and how it relates to the world, since most models take a non-linguistic form (e.g. maps, diagrams, scale-models). As the propositional component of a theory, hypotheses are truth-evaluable. Models themselves do not have a truth-

largely agree with her methodological position, with one reservation: metaphysicians of mind have a much greater overlap in subject matter with their scientific counterparts in cognitive psychology and neuroscience, than metaphysicians of material objects do with their physicist counterparts. Accordingly, I directly engage with models in the sciences, taking philosophical theories of time perception to be sharing a set of problems with those models.

¹⁴⁰ This metatheory of theories, *constructive realism*, is developed and defended by Giere (1988, 1999), but as far as I know, I am the first to apply it to the theories of temporal experience. For opposition to constructive realism see van Fraassen (1980), and see Giere (1999: 174-199) for a thorough contrast between constructive realism and van Fraassen's constructive empiricism. Additionally, my construal of theories as models borrows insights from the so-called "structuralist program" in philosophy of science, cf. Suppes (1967), Sneed (1971), Stegmüller (1976), Balzer, Moulines, and Sneed (1987), Bickle (1998), Moulines (2001, 2006).

value, but hypotheses can make true or false claims about the functional organization of a target system. A hypothesis linking a model to its target system entails predictions about the function and behavior of that system under various conditions.

Constructive realism is a model-based approach to explaining theories of temporal perception, which exploits some insights from the structuralist program in the philosophy of science, a class of related views that share two principal assumptions: (1) scientific theories are properly conceived of in terms of their models rather than in terms of sets of sentences; and, (2) the tools for formally explicating the structure of a scientific theory are provided by mathematics, *not* first-order logic or metamathematics (Bickle1998: 58-61).¹⁴¹ The first of these assumptions is the most important for my purposes, because it marks the departure from logical positivism which identifies scientific theories with sets of propositions formalized in first-order logic.¹⁴²

On the positivist conception of science, scientific representation is understood as a two-place relationship between statements and the world, whereby a theory's hypotheses are either true or false given the total available evidence. On the model-based approach, however, scientific representation is a relation between agents with particular purposes and some target phenomenon. This can be captured in the form: *S* uses *X* to represent *T* for *P*; where *S* is some agent(s), *X* is a theory that consists in certain principles that inform structural devices (i.e. models), *T* is some target phenomenon, and *P* is some purpose. Since models represent in terms of similarity of structure relative to some purpose, they are better evaluated in terms of degree of fit with the available data. We have better and worse representations given our purposes, not true or false ones.

¹⁴¹ The various proponents of the structuralist program prefer different mathematical formalisms to explicate the structure of theories. van Fraassen (1972, 1980, 1987) and Suppe (1974) endorse a geometrical state space approach; Suppes (1956, 1967), Sneed (1971), Stegmüller (1976) prefer set theory; Balzer, Moulines, and Sneed (1987) and Bickle (1998) prefer set theory augmented with category theory; Giere (1988) prefers the computational formalisms in cognitive science.

¹⁴² Cf. Carnap (1928, 1938); Popper (1935); Reichenbach (1938); Hempel (1950)

One normative criterion for evaluation is how well the structural features represent the system in question or *goodness of fit*, which comes in degrees. Ronald Giere claims, “to say a model is “true of” a particular real system in the world is to say no more that it “fits” that system or “applies to” that system” (2006: 65). No model represents every aspect of a target system, and explanatory purposes determine which aspects and to what degrees a given model should represent. Accordingly, a model might trade good fit to one respect of the system for a deformation or elimination of another negligible respect, relative to its purposes. For example, I expect a topographic map of a National Forest to represent the grade and relative elevation of the target terrain using contour lines—suited to the purposes of navigating the environment— but not the height of particular trees or groundcover texture.

A related point about norms of model evaluation is that, “the fit of a model to some real system is a matter of comparing aspects of the model not with data directly, but with a model of the data. It is a model-model comparison not a model-world comparison. And, of course, there may be several different legitimate ways of analyzing the data to obtain a model of the data” (Giere 2006: 68). Topographic maps can be drafted from field surveys and annotated aerial photography, which provide detailed models of the data against which the accuracy of the map can be judged. In the 21st century, however, models of the data are now constructed using GIS (geographic information systems) digitized data capture techniques, e.g. producing vector data from stereo pairs of digital aerial photographs often taken by unmanned drones.¹⁴³ The cardinal mistake is to think that GIS methods directly create a model of the world from raw data; rather, data capture techniques create models of the data from which models of the world can be generated and checked against by experiment (see Peschard 2010, 2012 and van Fraassen 2012 for the role of models in

¹⁴³ See Chang (2010) for a comprehensive introductory text on GIS, Goodchild (2010) for a survey of the progress made over the first twenty years of GIS research.

experimentation). The various ways of modeling the data provide different constraints on the resulting models and different norms for their accuracy. Theories of temporal perception also differ along these lines, since how one characterizes the phenomena and what constraints one builds into the target system largely determines the structure of the model.

Model evaluation always involves a model-to-model comparison and models of data are constitutively dependent on choices made concerning how to collect and analyze the data, relative to our explanatory purposes. If no unified model exhausts every possible combination of data capture and analysis techniques, or every possible combination of explanatory purposes, then no single model captures every feature of the target domain in all explanatorily relevant respects. Models constructed for different purposes can tell us different things about the very same system. It follows that there is no single uniquely true model of the data or model of the world. Models are better or worse approximations that make problems manageable and improve our understanding, hence the need for multiple interconnected or overlapping models. The proprietary hypotheses and principles invoked by a given model, however, are true or false in various respects and degrees—providing grounds for rejecting false hypotheses and locating common ground between contending hypotheses and principles.

From Giere's account, I adopt the view that a scientific theory is comprised of its models, i.e. families of structures specifiable by formal principles, as well as theoretical hypotheses that generalize from observational data which, in turn, connect the models to real physical systems in the world. To specify the relationship between the model and the target system, Giere employs a *similarity* relation to determine the respects in which a given model resembles the real system. He explains:

A theoretical hypothesis asserts the existence of a similarity between a specified theoretical model and a designated real system. But since anything is similar to anything else in some

way or other, the claim of similarity must be limited (at least implicitly) to a specified set of respects and degrees. (1988: 93)

Giere's sentiment echoes a common refrain found in Quine's metaphysics of science. Namely, that notions of similarity and simplicity are parochial (cf. Quine 1966: 234). What is simple and salient to one domain of discourse is a complex convolution for another. So, we must specify the scope and purposes for which a model is constructed and evaluate the attendant theoretical benefits accordingly. Since we represent things in science for particular purposes, which come in degrees, the similarity of a model to its target is judged in relation to the purpose for which the model is constructed and the respects of the target being modeled, where the target is some real system. As such, there are pragmatic advantages to adopting the model-based approach, since it more accurately tracks model-building practice in the sciences.¹⁴⁴

According to constructive realism, there are both top-down and bottom-up constraints that determine the empirical adequacy of a given theory and its models. Presently, bear in mind that we are only concerned with models in cognitive neuroscience, although these general points about model-building can be extended into other scientific domains. Bottom-up constraints are determined by the contingent limitations of physical implementation, such that the model can be plausibly realized by neural mechanisms. In this respect, bottom-up constraints are evidentiary, and not typically explanatory. Top-down explanatory constraints include the observable phenomena and specific effects exhibited by the cognitive system under investigation; these phenomena frame the scope of what the theory is intended to explain, i.e. its *explananda*. In practice, a model-based approach is an effective analytic method for generating explanations of how cognitive systems solve particular problems. Nevertheless, a single model is usually

¹⁴⁴ Cf. van Fraassen (1980: 65-67, 1987: 114-18) and Giere (1988: 62, 81-89)

insufficient to adequately represent and explain all features of a complex system, which is, in part, why I argue that a theory should be conceived of a family of models. In fact, we should find it extremely surprising if a single model could provide a detailed representation of all sets of phenomena. In the next subsection, I present the target phenomena that serve as constraints on a viable theory of temporal processing and perception.

4.6. The Target Phenomena to be Captured by Models of Time Perception

Theories of temporal processing are developed to provide mechanistic explanations for a wide range of target phenomena and reliably manifested perceptual effects. A theory's models ought to represent structures that can account for these phenomena, which include both reliable representation and systematic misrepresentation of temporal structure by human subjects under specifiable conditions. Although the list is not exhaustive, each of the following target phenomena signifies a theoretical desideratum for candidate models of time perception, particularly concerning our experience of duration:

- a) *Sub-second Discrimination*: Humans, and other animals, are able to discriminate intervals and durations on the millisecond timescale.
- b) *Reliable Temporal Reproduction*: Human performance on temporal reproduction tasks for stimuli falling within the range of the temporal integration window (500ms-3s) is reliably accurate.
- c) *Suprasecond Performance Deficit*: Human performance on temporal reproduction tasks for stimuli >3 seconds exhibits a systematic shortening, i.e. there is a systematic degradation of accuracy on reproduction tasks for durations greater than three seconds.
- d) *Subjective Time Dilation*: Human subjects sometimes experience a stimulus or event lasting longer than its objective duration. This effect is reliably manifested when the stimuli are more complex, infrequent, unexpected, increased in some spectral magnitude (e.g. brightness or amplitude), or affectively salient. For example, if a subject is shown an

oddball stimulus after a series of similar stimuli, she will perceive the oddball stimulus as being longer in duration than the repeated stimuli.¹⁴⁵

- e) *Subjective Time Compression*: Human subjects sometimes experience a stimulus or event as briefer than its objective duration. This effect is reliably manifested when stimuli are simpler, frequent, expected, or decreased in spectral magnitude. For example, if a subject is presented a series of identical stimuli like several tones of exactly the same frequency and duration, she will perceive the latter stimuli as being shorter in duration than the initial stimulus.¹⁴⁶

One might wonder why phenomena (a-e) should constrain *philosophical* theories of time perception. The first reason is simply that most of these phenomena are recognized as salient in phenomenological accounts of temporal experience. Recall that philosophical theories of time perception are motivated by our capacities to perform complex motor actions and engage in projects that require fine temporal discrimination, such capacities corresponding to (a) subsecond discrimination and (b) reliable temporal reproduction. Introspective evidence also reveals subjective time dilation and compression effects, that is, (d) and (e) respectively. For example, experiences of time dilation abound, such as persons in vehicular accidents typically report a feeling of time "slowing down" as the collision occurs, and athletes in clutch performances report a feeling of time "slowing down" as aiding them when performing excellently.¹⁴⁷ A perspicuous phenomenology of temporal experience will therefore be able to recognize and describe these various phenomena as informing their account, and such introspective evidence continues to guide psychological and neuroscientific investigations into time perception.

¹⁴⁵ For studies of the oddball time dilation effect, see Tse et al. (2004), Paryadith & Eagleman (2007), Eagleman & Paryadith (2009), van Wassenhove et al. (2011)

¹⁴⁶ You can see this for yourself by looking at an analog clock with a second-hand. When you first direct your attention to the clock the first tick of the second-hand will appear to last longer than the successive ticks.

¹⁴⁷ Michael Jordan claims that during some of his greatest feats, e.g. in the NBA finals, he seemed to be going in slow-motion which enabled him to out maneuver opponents when driving to the basket.

A second reason for paying attention to the types of time experiences described in (a-e) is that phenomenological theories on their own do not, in my view, have the resources necessary to *explain* these psychological effects. For example, Heidegger (1927) argues that phenomenology is the guide to fundamental ontology, meaning that he purports to derive the necessary conditions for the possibility of experience.¹⁴⁸ Yet although such transcendental arguments may yield a metaphysical model, they cannot yield a functional one. Providing useful models of specific physical mechanisms is simply not at the same level of description as “big-tent” metaphysics. Thus, if we want to know *how* we process temporal information in perception, then we require a scientifically informed account. If we want to understand the structure of the competing scientific theories, then a model-based approach provides the best method for such understanding.

In order to provide explanations of the target phenomena (a-e), a theory's models posit cognitive mechanisms or integrated networks by which the cognitive system can process and represent temporal input; transforming and integrating those representations in the elaboration of perceptual content.¹⁴⁹ Models are analytic tools, and they earn their keep by the sorts of problems they can negotiate in practice – implying that they are selected against when their deficiencies outstrip their advantages. If so, we should let the models play out in the intended domain so as to investigate whether or not they make the problems of temporal perception tractable. In the next section, I distinguish between two families of neurocognitive models concerning the perception of duration and begin a preliminary investigation into their relative merits and shortcomings, in order to pave the way for future interdisciplinary work in the domain of temporal perception.

¹⁴⁸ “*Only as phenomenology, is ontology possible.* In the phenomenological conception of ‘phenomenon’ what one has in mind as that which shows itself is the *Being* of entities, its meaning, its modifications and derivatives.” (1927/1962: 60, H. 35, original emphasis)

¹⁴⁹ Explaining how such transformation and integration works is a special case of the perceptual binding problem. For discussion of the binding problem and evidence for feature integration theory see Treisman (1988, 1993), Treisman & Gelade (1980), Treisman & Gormican (1988).

4.7. A Brief Comparison of Dedicated Models and Intrinsic Models of Temporal Processing

Prior to examining specific cognitive models of timing processes, it is important to organize the logical space of possible models by marking a deep division between two broad families of models: *dedicated* vs. *intrinsic* models.

A *dedicated* model posits a class of structures to explain the singular function of timing perceptual input, i.e. a mechanism or system of mechanisms devoted to processing the duration of stimuli. A *dedicated* model therefore simply proposes a timing device in the brain (and nothing more) that somehow measures and processes temporal information from sensory input and makes that information available to other dedicated subsystems, such as those responsible for executing perceptual judgment or motor control.

An *intrinsic* model, in contrast, represents timing as an ongoing process that is one subroutine of a more general mechanism for processing perceptual information. According to this family of models, the brain is always encoding temporal information, but this function does not involve a dedicated timing mechanism. Rather timing is an inherent feature of neural subpopulations. For example, on one set of intrinsic models, temporal information is encoded in the spatial firing patterns of neural networks dedicated to processing other sensory information, like visual or auditory input (Karmarkar & Buonomano 2007). On other intrinsic models temporal information is extracted from other magnitudes, such as the amount of energy expended by a given subsystem to process a particular set of stimuli (Eagleman & Pariyadath 2009). Consequently, on this type of model, duration is viewed as a function of how much energy it took to process and integrate information about the target event. For intrinsic models, timing is context dependent and modality specific. For instance, it is an intrinsic property of auditory processing that realizes functions for

representing timing in audition, and likewise for other modalities. There is no general purpose timing mechanism for intrinsic models, as there is for dedicated models. This makes intrinsic models notoriously ill-suited for explaining evidence of humans to make accurate cross-modal comparisons of duration.

It remains to be seen whether dedicated and intrinsic models are completely incompatible with one another, or whether cognitive systems deploy different timing strategies in response to different types of phenomena. For example, audition and vision differ with respect to fineness of temporal grain, such that auditory information can be processed with greater resolution.¹⁵⁰ This gives us *prima facie* reason to seriously consider the possibility that the auditory system could employ a more efficient timing strategy than, say, the visual system, in response to the fine temporal parameters of audio signals. For example, millisecond information could be extracted from intrinsic features of perceptual subsystems, whereas longer durations and multi-modal representations are computed by a dedicated timing mechanism. At the same time, multi-modal perception poses a significant challenge to theories that attempt to combine approaches, because subjects perform well on cross-modal timing tasks within the temporal integration window, i.e. subjects are reliably able to compare the duration of a tone to the duration of a presented image. Future research is required to determine whether the multi-modal challenge can be overcome with a hybrid combination of dedicated and intrinsic models of temporal processing. The framework of constructive realism is compatible with such a solution, since it recognizes how multiple overlapping models and their proprietary hypotheses constitute theories.

¹⁵⁰ Dedicated “internal clock” model theorists hypothesize that the difference in auditory and visual temporal discrimination is due to the internal clock or pacemaker running at a faster rate when the stimulus is auditory than when it is visual (Penney et al., 2000; Wearden et al. 1998). An alternative hypothesis is that there are distinct timing mechanisms for auditory and visual modalities. Parallel distributed processes operate on distinct timescales simultaneously which require a further process or processes for integration and buffering.

If temporal information were processed in fundamentally different ways by the visual and auditory systems, we would not predict subjects to reliably compare the relative durations of different types of sensory input. Other things being equal, we should also prefer a theory that employs a small number of fundamental principles to explain a broad range of phenomena, what Quine (1966) calls the theoretical virtue of *familiarity of principle*. This epistemically conservative principle is seemingly violated by theories that help themselves to both intrinsic and dedicated models, since different kinds of timing strategies employ distinct principles introducing needless complexity into the theory. If one model can accurately predict performance on both modality-specific and cross-modal timing tasks, then, all things considered, we should prefer a single type of timing mechanism over a motley combination of timing strategies. For the present purposes, I will treat the two families of candidate models separately, while leaving open the possibility of hybrid models.

A second division in logical space between types of timing models concerns whether the durations of events are computed over *localized* or *distributed* networks.¹⁵¹ Localization and distribution is a matter of how a model is physically implemented in an actual system. A *localized* model, on the one hand, identifies a particular region of the brain or a particular neural network as realizing the salient structures. Typically a localized model is also a dedicated model which identifies components of the timing mechanism as being implemented in a certain region of the brain, like the basal ganglia. A *distributed* model, on the other hand, identifies temporal processing as taking place in separated and, in principle, dissociable regions of the brain. A distributed dedicated model, for example, posits several dedicated timing mechanisms distributed in different neural networks across the brain. Intrinsic models are typically also distributed, since temporal

¹⁵¹ Cf. Ivry & Schlerf (2008).

information is continuously encoded in neural processes taking place in various subsystems. Mounting empirical evidence strongly favors distributed processes, regardless of whether one's elect models are dedicated or intrinsic. Nonetheless, since the localized hypothesis is not dead, I will present the difficulties that arise for such models and offer alternative ways of interpreting some of the research that is marshaled in favor of localized theorizing as we look at particular models.

At this stage, I only offer a brief exploratory analysis assessing the merits and potential problems of the dominant dedicated models, and make a few relevant comparisons to the alternative intrinsic models. Dedicated models of time representation, as mentioned above, pursue a fundamentally modular strategy for explaining the ability of cognitive systems to process temporal features of the environment. A modular strategy postulates that cognitive tasks are accomplished via specialized networks or neural pathways that are dedicated solely to those particular tasks. A dedicated model may therefore be described as employing a "divide and conquer" strategy. Just as visual modules are for visual processing and auditory modules are for auditory processing, dedicated models assume that certain brain structures are devoted to the function of processing temporal information. These theories suggest that there is a specific representational scheme for internal timing, but that this scheme is perfectly general such that the same mechanism is operative regardless of the modality of sensory input. That is, it does not distinguish between, say, auditory temporal data (e.g., the duration of a tone) and visual temporal data (e.g., the duration of a flash); it processes all temporal information in the same manner for both modalities.

For the last three decades, cognitive psychologists have widely endorsed an *internal clock model* (ICM) of temporal processing (Church 1984, R. Block 1990, Wittman 2009), which

continues to occupy a majority position within the field (cf. Rammsayer & Ulrich, 2001, Grondin 2001, Wearden, 2004). This relatively simple model posits that temporal processing has the structure of a gated internal timer (a pacemaker) operating on an oscillatory basis. The intuitive appeal of this model derives from our use of pendulum clocks to keep time, since such clocks measure temporal magnitudes via the regular oscillations of the pendulum. In ICMs, attention and external stimuli influence the gating of the pacemaker which, in turn, generates trains of discrete pulses at a constant rate encoded in an accumulator and updated to working memory for comparison. The mechanism is a simple circuit that closes at the onset of an attended stimulus and accumulates a regular number of pulses like ticks on a stopwatch. At the offset of the stimulus, the gate opens and the pulses no longer accumulate. The mechanism of the internal clock model can be illustrated in the following ways:

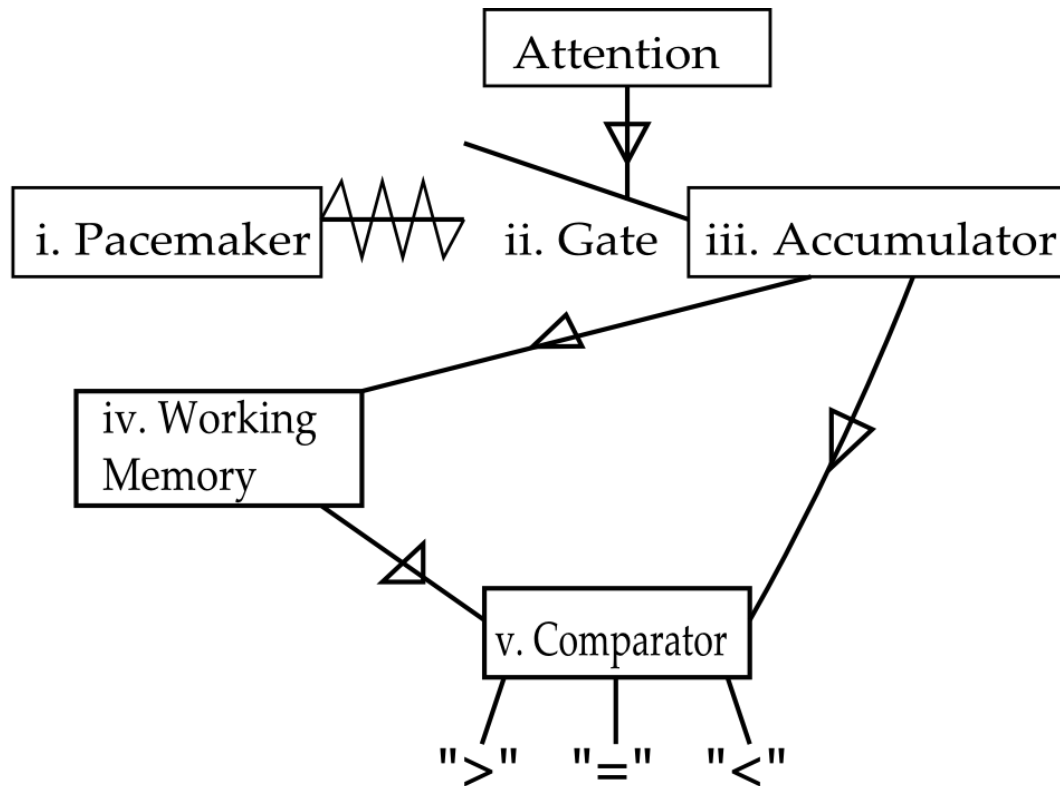


Figure 5: *Simple Internal Clock Model* with (i) a pacemaker mechanism that generates regular oscillatory pulses to time a target stimulus, (ii) a gated switch that controls pulse train throughput, (iii) an accumulator that encodes pulse train frequency when the gate is closed and updates timing information to (iv) working memory that stores accessible representations of stimuli duration for (v) a comparator component that judges relative duration of a target stimulus or compares the duration of distinct stimuli.

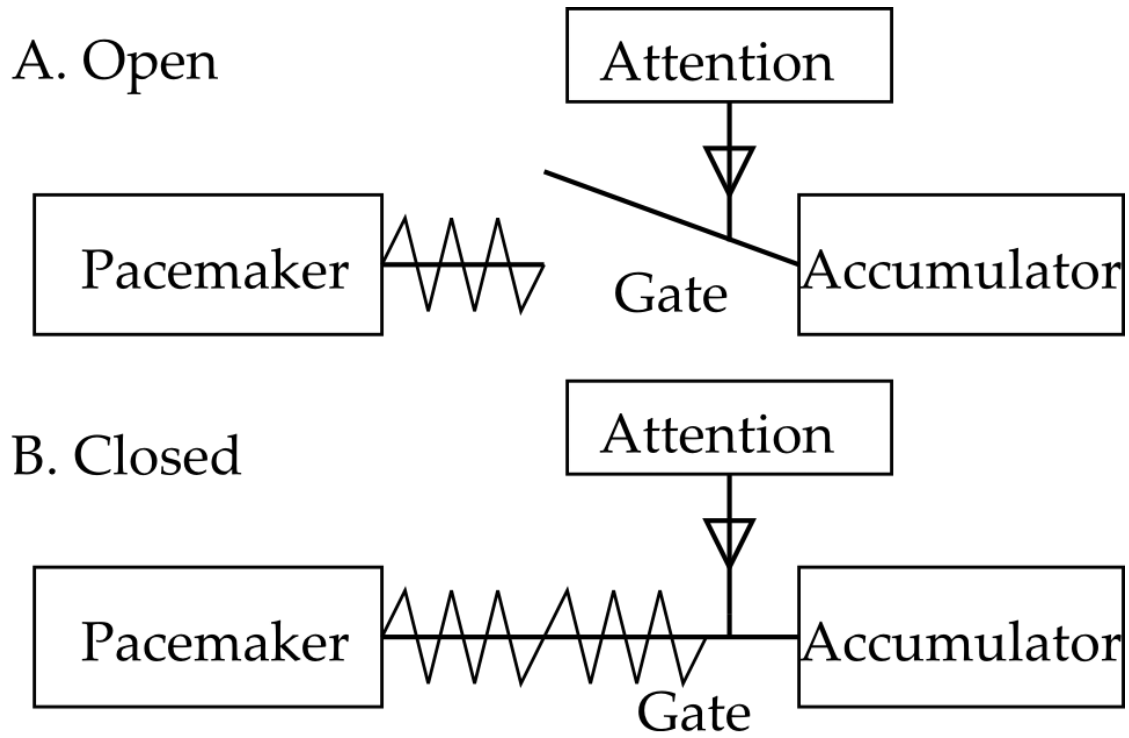


Figure 6: *Attentional Gating Mechanism* (A) models a simple internal clock with an open gate, so that the pulse trains from the pacemaker are not being encoded in the accumulator. (B) shows the internal clock with the gate closed by attention, i.e. the perceptual system attends to a target and times the stimulus by encoding the pulse train frequency until the gate is reopened when attention lapses or shifts to a new target.

One prominent ICM - the pacemaker-gate-accumulator model - posits a dedicated timing mechanism that encodes temporal durations as cumulative pulse counts A , which are the product of the intervals of presented temporal stimuli t and the effective pulse train frequencies f , such that $A = t \cdot f$ (Zakay & R. Block, 1997). According to the model, as depicted in Figure 5, the accumulator pulse train counts are then updated to working memory and made available to the comparator component of the timing mechanism in order to inform perceptual judgments and motor actions with respect to the duration of a stimulus. The function of the comparator component is analogous

to how a human subject reads off conventional metrical units on an external timing device such as a clock. Comparative differences in the pulse train frequencies f recorded in the accumulator represent variations in timing behavior or variations in time perception task responses.

One of principal motivations of such dedicated ICMs is that temporal perception is not seen as restricted to a single sensory modality. There is no sense organ for time, but implicit timing takes place across all modalities. By contrast, as I noted above, intrinsic models are typically limited by context dependency and modality specificity. The temporal reproduction paradigm is used to measure our capacity to reproduce an auditory or visual stimulus using the press of a key, which is itself a cross-modal sensorimotor behavior. Our general proficiency at such tasks indicates that temporal perception is not a modality specific mechanism. As Richard Ivry and John Schlerf note, “our sense of passage of time appears to transcend the sensory modality of a stimulus... The facile manner with which we compare time across different modalities suggests some sort of internal clock” (2008: 273). Some studies explicitly test cross-modal temporal discrimination, for example, comparing the duration of a sound to the duration of a presented image.¹⁵² Such studies bolster support for a common dedicated timing mechanism for processing temporal information across modalities. So, with respect to temporal discrimination in cross-modal tasks and perception, dedicated models maintain a significant advantage over intrinsic models.

The simplicity of the ICM is, however, also one of its major drawback, because the gate and pacemaker are arranged serially and thus the model cannot distinguish between the effects of the two different components. This makes it difficult to dissociate endogenous effects on the

¹⁵² Rolf Ulrich and colleagues (2006) specifically set out to test the predictions of the pacemaker-accumulator ICM. Using a standard temporal reproduction task, subjects were required to discriminate between the duration of a constant probe stimulus and a variable comparison stimulus. In congruent trials the probe and the comparison were either both auditory stimuli or both visual stimuli, whereas in the incongruent trials the probe and comparison were presented in different modalities (i.e., either audio-visual or visual-audio). Subjects perform better than the model predicts for congruent trials, but the model uses a complex psychometric function to accurately predict that subjects perform better on v-a incongruent trials than on a-v incongruent trials.

pacemaker pulse rate (e.g. neural dynamics or electrochemical properties) from cognitive effects on the gating (e.g., response task, stimulus modality, distribution of attention, working memory capacity).

“The effective frequency f may vary due to a change of the pacemaker fundamental frequency f_P (e.g., in response to organismic, physiological factors), or due to a change of the gate through-put g (e.g., attentional, cognitive effects): $f = f_P \cdot g$ (where g is a real number in the range from 0 to 1).” (Sysoeva et al., 2011: 1)

For example, an ICM must postulate that the pacemaker accelerates pulse train frequency in cases of *subjective time dilation* and decelerates pulse train frequency in cases of *subjective time compression*. Some ICM theorists assume that the brain, and thus the pacemaker, has access to its own internal rate of information processing, which usually fires at a constant rate. They suggest that under duress, or increased attentional load, the overall information processing accelerates, thereby increasing the pulse train frequency of the pacemaker and causing subjective time dilation effects.¹⁵³ These theorists employ this strategy to account for oddball effects, where an oddball stimulus is judged to be longer when presented to subjects in a sequence of identical stimuli. Accordingly, the appearance of an oddball stimulus after a sequence of identical stimuli increases arousal and attention, accelerating the rate of the internal pacemaker, thereby causing the subject to judge the duration of the oddball to be longer than the preceding stimuli. Notice, however, that this hypothesis postulates a complex interaction of physiological (i.e. arousal, processing rates) and cognitive (i.e. attentional load) factors, and thus confounds the effects of the pacemaker and gating through-put. This multiplication of auxiliary hypotheses also appears to violate the familiarity of principle desideratum for scientific theories.

¹⁵³ Cf. Rose & Summers (1995), Ranganath & Rainer (2003), Tse et al. (2004), Ulrich et al. (2006).

The second major drawback of dedicated ICMs is that there is no plausible neural implementation of the model. This is not for a lack of trying to locate the ICM. Recall that dedicated models are typically localized models; ICM researchers often marshal evidence from neuroimaging studies (PET and fMRI) to point to some region of the brain to correlate with the activities of the dedicated timing mechanism. For example, the *cerebellar timing hypothesis* posits that the cerebellum has the unique representational capacity required for implementing temporal processing, and cerebellar networks are accessed whenever precise timing is required.¹⁵⁴ Nevertheless, structurally similar arguments have been made in favor of other neural regions uniquely realizing a dedicated timing mechanism, such as the supplementary motor area¹⁵⁵ and the basal ganglia.¹⁵⁶ These conflicting hypotheses and the evidence in favor of all of them, provide reason to think the localized models are empirically inadequate, and distributed models are preferable.

A final problem is that whether or not the localization question can be settled, dedicated ICMs do not have an accompanying story of how a neural population realizes a pacemaker, gate, accumulator, or comparator. That is, ICMs violate the bottom-up constraints imposed by the contingent properties of neurophysiology, failing the physical realization level of cognitive analysis. Theorists have developed complex algorithmic formalizations in order to fit the ICM to the diverse behavioral data, including subjective time dilation and compression. Nevertheless, without a plausible way for neural subpopulations to physiologically realize these functions, the ICM remains a mathematical model, not an actual model of the target cognitive process, namely duration perception in humans. In response to this failure of dedicated models to find an adequate

¹⁵⁴ Cf. Ivry et al. (2002), Ivry & Keele (1989), Mangels et al. (1998), Ackermann et al. (1997)

¹⁵⁵ Cf. Coull et al. (2004), Macar et al. (2006)

¹⁵⁶ Cf. Harrington et al. (1998), R.P.N. Rao et al. (2001)

neural implementation, many cognitive neuroscientists are developing alternative *intrinsic* models of temporal processing that are largely constrained by neurophysiology at the outset. We should note that these bottom-up constraints are evidential, not explanatory. So, failure of realization rules a model out on evidential grounds. Successful implementation, however, adds nothing to the explanatory contributions of the model, whose target is the various observable effects in temporal perception like subjective time dilation and compression. The model itself explains these effects, whereas the physical implementation does not.

Obviously, in this brief section, I have not exhaustively assessed the competing models of duration processing, but I have begun the process of scouting the alternatives and flagging potential problems. In this manner, the ongoing development and future iterations of content extensionalism will be informed by the ongoing research that might provide insight into exactly how multi-scale sampling and integration is physically realized by sensory subsystems.

4.8. Concluding Remarks on Future Interdisciplinary Collaborations

Why should philosophy of mind pay attention to these alternatives? Philosophical analysis of time perception is concerned with the temporal structure of experience and our cognitive capacities to process and represent temporal properties and relations of events. If we grant physicalism, then conscious experiences supervene on physical states of the cognitive system at any given time. So, philosophers have a stake in determining what the cognitive system looks like, how it processes temporal information, and how to best model that system. Given that there is a live dispute in cognitive science as to whether duration processing is best modeled as dedicated neural timing mechanisms or whether temporal information is encoded ubiquitously in intrinsic features of state-

dependent processing, philosophers should examine the available evidence and evaluate the candidate models themselves rather than uncritically defer this question to the scientists.¹⁵⁷

This dispute is also of interest to the philosopher because the reliability of our cognitive timing processes bears on the question of how we represent order and duration in ways that make possible fine temporal discrimination and complex coordinated behaviors; the target phenomena that I identify above in §4.6. In addition, philosophical analysis and novel interpretations of the experimental findings may also generate new solutions or help rule out the plausibility of a particular competing model. Empirically informed philosophers ought to take part in science, rather than being mere handmaidens performing the thankless task of conceptual analysis. On the view I am pushing, philosophers of science are not merely reading off the ontology from some dominant model and offering a semantics for it, rather we ought to be working alongside the primary investigators by evaluating the relative merits of incommensurable models and offering up testable hypotheses that might rule out contenders. Furthermore, I claim that model choice in the domain of temporal cognition imposes constraints on the plausibility of philosophical theories of time perception. I suggest that our best strategy for adjudicating the model choice dispute with respect to temporal cognition involves seeing how the particular models fit the introspective and experimental data, what predictions they entail, and then, on this basis, determine the merits and deficiencies of each contender.

I am concluding the dissertation with this interdisciplinary upshot for the philosophy of cognitive neuroscience, because I believe it highlights fruitful possible avenues for collaborations

¹⁵⁷ See Ivery & Schlerf (2008: 273-280) and Wittman (2009: 1955-67) for detailed discussion of the competing models, reviews of the relevant experimental paradigms, and outstanding problems for each candidate. In an earlier chapter, I directly engage this debate, since Le Poidevin (2007: 109-122) argues that any of the candidate models support his epistemological conclusion about the formation of perceptual beliefs about duration, which I challenge on other grounds as well.

between philosophers and neuroscientists working within the domain of temporal perception. In the first half of the chapter, I argued that behavioral neuroimaging research on speech processing lends some confirmation to the MSS hypothesis postulated on my version of content extensionalism. I welcome the possibility to directly test MSS, and further refine my model. I also argue that atomism and its ASC hypothesis are inadequate to explain some of the relevant experimental data, but more needs to be done to test the viability of atomistic sampling. If we are invested in the broader enterprise of understanding temporal perception and how it is functionally realized in the human neural architecture, then we have an intellectual obligation to continually seek ways to improve our models and hypotheses.

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